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in
Invertebrate Zoology

for

(B. Sc. Students of Indian Universities)

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PREFACE SECOND EDITION

We are extremely glad to place in the hands of our patrons, the lovers of Zoology, this fresh print of the well known book 'A Brief Course in Invertebrate Zoology' by Prof. Murli Manohar Saxena. We thank all our patrons in gereral and the B. Sc. Biology students and teachers in particular for according so nice a reception to the book that its entire first print was sold within one year of its publication.

This fresh print presents two additional chapters dealing with 'The Cell' and 'The Cell-division' and it is hoped the readers will welcome this 'new edition' with redoubled interest.

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PREFACE FIRST EDITION

This book will cater to the needs of all those B. Sc. students who for some reason or the other, wish to be 'brief' in their study and yet 'bright' in their results. Selected topics from the entire Invertebrate Zoology have been dealt with as concisely as could be done without omitting the vital points of interest. All along, an earnest effort has been made to render the book intelligible even to those who happen to 'start with this book' without having made enough preparation from other sources beforehand. The students intending to have a brief resume of their previous preparations or who wish to depend upon an 'intelligent selective study, or still others who, after having made ample preparations from voluminous books wish to acquire the 'art' of 'concised expression' with a 'scientific precision' carrying maximum of meaning in a minimum number of works, will all find the book particularly helpful to them. However it would be advisable to recommend one caution to the readers and that is : at least this small book should be read fully and that no further selection be made out of its already selected contents.

Suggestions for improvement of the work along with criticisms from the professors as well as the students would be gratefully acknowledged and I shall feel obliged to all those who extend their interest in this book and favour me with their valuable opinions. Those who wish to make a more detailed study of the Invertebrate Course may refer to my Text book of Invertebrate Zoology (1963 Edition) which has been released earlier.

Like my other undertakings, in the production of this book also, I received valuable help from my elder brother Sri Shyam Manohar Saxena, B.A., L.T., LL.B., and Bhabhi Mrs. Usha Saxena. To the publishers I am thankful for their efficient management in converting the manuscript into the printed book in a short time.

MURLI MANOHAR SAXENA

IN CHERISHED MEMORY OF
PROF. DARA M. MUNSHI
FORJET STREET, [illegible]

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1

Introduction

The entire organic world is made up of two types of organisms: (i) **animals** and (ii) **plants,** which constitute two *kingdoms* or the primary sub-divisions of the 'living world'. An all-sided inquiry into the affairs of the animal kingdom forms the subject matter of **Zoology** which is therefore rightly defined as the *science of animal life.*

An animal is an organised being having life, sensation and voluntary motion. Plants too have life, but compared to them animals are more active and responsive to stimuli; the animals possess muscular and nervous systems for such a response. Plants completely lack muscles and nerves and are therefore *apparently* passive and inert. The plants possess firm, cellulose cell-walls and chlorophyll. Amongst animals chlorophylls is found only in some of the Protozoa. Firm and definite cell walls are usually lacking in animals. The plants usually build up organic substances from inorganic materials by an elaborate process known as photosynthesis. The plants are thus mainly *holophytic* or *autotrophic.* On the other hand, the animals feed on complex organic materials having thus a type of nutrition known as *holozoic*[1] or *heterotrophic.* Amongst unicellular organisms, the *Protozoa* are animals and the *Protophyta* are plants. The protozoa normally nourish themselves by the *holozoic* mode of nutrition but their recognition from the unicellular plants is by no means easy, there being hardly any characters clearly separating the Protozoa from the protophyta.

It has been customary to use the terms *Vertebrata* and *Invertebrata,* but strictly speaking, these do not constitute the true and primary divisions of the animal kingdom. The Animal Kingdom is in fact truly divisible primarily into three unequal sections namely (i) *Protozoa* (ii) *Parazoa* and (iii) *Metazoa,* each of which is ranked as a sub-kingdom.

The protozoa differ widely from the Metazoa in their organization and the main points of difference are as follows—

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[1] *Holozoic*; the mode of nutrition in which an animal ingests other living organisms or any other solid organic food is known as the holozoic mode of nutrition; in this method complex organic substances are swallowed through a temporary or permanent opening serving as mouth.

Protozoa	Metazoa
1. Are without cellular differentiation; often described as unicellular, but are truly acellular or noncellular. In other words, their body is not differentiated into tissues composed of cells.	1. Cellular differentiation is strongly marked; i. e. the body is composed of many cells.
2. Photosynthesis occurs in many of the Protozoa.	2. Photosynthesis is completely absent.
3. When a protozoon has more than one nucleus, no nucleus controls a specialised part of the cytoplasm.	3. There are always many nuclei in their body and each nucleus controls a particular portion of cytoplasm which performs a specialised function.
4. They are mostly minute and microscopic in size.	4. These are mostly large in size as compared to Protozoa.
5. Their organs are intracellular. These intracellular organs are called *organelles*.	5. Their organs are cellular and are composed of many cells.
6. Compared to metazoa, their structure is simple.	6. The component parts of body exhibit a very high degree of differentiation and specialisation; morphological differentiation is far greater than that in Protozoa. Their morphological complexity is accompanied by an equally elaborate physiological division of labour.
7. Generally, it may be stated that all the cytoplasm of their body is of a generalised nature and retains powers of sensitivity and conduction and also of forming the receptors.	7. The effector structures usually lie at a distance from the receptors. As a result, a special system: the nervous system is developed which holds charge of conduction and co-ordination.
8. In the bodies of Protozoa, the dead 'formed' material never assumes the importance of a *ground substance or skeleton* comparable to that of Metazoa.	8. Such ground-substance or skeleton is commonly met with.
9. Their life cycle usually comprises more than one generation.	9. This is rare among metazoa.
10. The animal nature is not very distinct in all of them. They present several more or less continuous series from wholly plant-like organisms through various links or intermediate forms to perfectly 'animal' forms, the perfect animal nature being exhibited in their *mode of nutrition* and *behaviour*.	10. Every metazoon is a perfect animal. The holozoic mode of nutrition, complete absence of photosynthesis, presence of muscular and nervous systems, sense organs and in higher forms, other specialised systems: vascular system, respiratory system etc. are also developed.
11. No embryonic development is found.	11. The life history includes an embryonic development.
12. Only one phylum, the protozoa is included in this subkingdom.	12. Except Protozoa and Porifera (sponges), all the phyla are included in Metazoa. Besides various invertebrate phyla, the vertebrates (under Chordata) also fall under this head. Thus all chordates and nonchordates (except the Protozoa aud Parazoa) belong to the subkingdom Metazoa.

The subkingdom **Parazoa** includes simple more or less acquatic plantlike fixed multicellular animals which possess collared-cells or *choanocytes*. It comprises a single phylum the **Porifera**. The body of these animals contains a single cavity lined by choanocytes. The body has numerous minute pores in the body-wall through which water enters in and one or more large openings through which water passes out. A calcareous, siliceous or horny skeleton is present.

Within the Metazoa, two distinct types of organization: the **Diploblastica** (coelenterata) and the **Triploblastica** are met with. We will now examine the main points of difference between these two.

Diploblastica	Triploblastica
1. The bodywall of these animals is composed of two	1. During their development in the embryo, there are

Diploblastica	Triploblastica
layers of cells: the outer *ectoderm* and the inner *endoderm*. The bodywall encloses a single cavity the *coelenteron* or *gastrovascular cavity* in which both digestion and circulation take place.	three germinal layers[1]: the *ectoderm*, *endoderm* and an intervening *mesoderm*. It is from these that all organs of the adult are developed.
2. These animals (the Coelenterata) typically start life as a simple two layered, ciliated larva, the *planula*. The animals may retain the two layered condition throughout life or late in the development cells of the ecto and endoderm immigrate into the space between these two layers: the *blastocoele*. The *mesoglea* between the ectoderm and endoderm is structureless and *usually* cell-less. In any case amongst the diploblastic animals the mesoglea does not form any organs.	2. A true mesoderm makes its appearance in the embryo at an early stage. The mesoderm forms important organs of the adult: muscles, connective tissue, blood vascular system, reproductive system etc. In many cases, the peculiar *parenchyma* or mesenchyme also developed from the mesoderm packs up all around internal organs e. g. in Platyhelminthes.
3. The coelenterates alone are the diploblastic animals. These animals have a single continuous space the *coelenteron* which opens to the exterior by a mouth opening. Digestion and	3. Under this we have two types of organization: the (i) **Acoelomata** in which there is *no* true body cavity or coelome and the (ii) **Coelomata** which possess a true bodycavity or *coelome*[2].

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[1] The adult organs in most animals do not arise directly from cells formed by division of zygote; at first the zygote divides to form many cells which get arranged in definite layers: the outermost layer is called the *ectoderm* (or epiblast), the inner layer called the *endoderm* (hypoblast) lines the gut and the third layer which lies between the ecto—and endoderm is called the *mesoderm*. It is from these layers of cells that the organs of the adult are formed. These layers are therefore known as germ-layers.

[2] "A true *coelom* can be defined as a space between the digestive tract and bodywall which is bounded by ento-mesodermal tissue and is lined by peritoneum". The coelom is a cavity in the mesoderm lined by an epithelium; into this cavity usually the excretory organs open and the reproductive cells originate from its walls.

Diploblastica	Triploblastica
absorption occur in this cavity which represents the digestive cavity as well as the general body-cavity. Separate body-cavity is never found.	All the metazoan phyla excepting the Coelenterata belong to this kind (Triploblastic) of organisation. The acoelomate phyla are Platyhelminthes, Nemertea, Rotifera, Nematoda, Gastrotricha, Acanthocephala and Nematomorpha. The coelomate phyla are Annelida, Arthropoda, Mollusca, Echinodermata and Chordata.
4. The animals have a tissue grade of organisation; all functions are performed by tissues and no organs are found in true sense.	4. These animals have an organ-grade of organisation. They have true organs.

The **Acoelomate** animals are unsegmented forms with mesenchyme and the space between the gut and the body wall (when present) is a primary[1] body cavity which has no definite epithelial boundaries and hence can be easily distinguished from a true coelom; this primary body cavity may be invaded by the mesenchyme cells, which in case of Platyhelminthes completely fill it and form the parenchyma; in case of Nematoda, the cavity is occupied by a small number of very large vacuolated cells whose vacuoles simulate a body cavity. A set of nephridial canals (which may be intracellular or intercellular) are found with their internal ends closed; in many cases *flame cells* are also found; the whole system is concerned with the regulation of fluid content of the body. These animals have a nerve net with an anterior brain and a few longitudinal nerves. Reproductive organs present considerable variation in different groups. The acoelomates possess definite organs to perform various functions and are more advanced in this character than the Diploblastica (Coelenterata) which stand at the tissue grade of organisation and which have no definite organs. In simpler acoelomates, the gut presents some points of similarity to the enteron of coelenterates. For instance, in the gut of Platyhelminthes (Flat worms) there is a single opening, the *mouth* serving to ingest food as well as to discharge faeces; anus is completely absent.

The **Coelomata** possess a true coelome. The *coelom*, when it arises as a pouch from the archenteron (e. g. Amphioxus) is known as an *enterocoele* and when it arises as a split in the mesoderm it is known as a *schizocoele*. The gonads are derived from the walls of coelom; the germ cells are shed into the coelomic perivisceral cavity (which surrounds the internal organs mostly) or the cavity of the gonad which is really a separated portion of coelom. The coelom also communicates with the exterior, by means of (i) *nephridia* which usually serve to pass out water containing excreta and (ii) *coelomoducts* which may serve in excretion and also in passage to the exterior of germ cells, or solely as reproductive ducts.

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[1] The primary body cavity represents the part of blastocoel which has not been obliterated by mesenchyme cells; it never contains germ cells and never communicates with the exterior.

The cavity (*the perivisceral cavity*) which surrounds the internal organs may be *coelomic* or *haemocoelomic*. In Arthropoda, the coelomic cavity is reduced to small cavities in the gonads and excretory organs while the perivisceral cavity is the haemocoele which surrounds the internal organs.

It is remarkable that coelom has played a prominent role in the progressive development of structural complexity amongst animals. Great physiological changes have occurred by the development of coelomic cavity between the digestive tract and the body wall. The development of nephridia for transporting waste products out of the body and of genital ducts for the exit of germ cells is correlated with the development of coelom. Excretory material gets into the coelomic fluid and thence out to the exterior through the nephridia. A new system; the *blood vascular system* has developed which takes charge of various vital functions: distribution of nutrition and oxgen etc.; this is essentially a consequence of the separation of the body wall and different organs from the gut due to the intervening coelome, for in this condition substances cannot reach the remote tissues of the body from the gut by diffusion. The organs of respiration providing large surface area for gaseous exchanges and the organs of excretion become elaborate. The size, in general of the coelomate animals also tends to increase. The nervous system becomes better developed and the tendency of a centralised control through the central nervous system becomes distinct: the brain assumes more distinct form. The sense organs become more elaborate and help the more complex animal to perceive, understand and react better and show greater success in adapting itself to environment. The locomotory organs and muscular system show a definite advance and as a result we get a 'behaviour' which reflects the all sided advancements briefly referred to above in the entire coelomata. The visceral organs are free to move and are bathed in the coelomic fluid which also protects them against mechanical jerks. The gut always has both mouth and anus and the gut wall is capable of peristaltic movements which are completely independent of the body wall. The alimentary canal becomes more efficient and attains a pronounced physiological division of labour (i. e. different parts perform definite functions) correlated with corresponding structural differentiations.

It must have become clear now that the coelomate animals present higher specialisations both morphological and physiological and an advanced level of complexity of form and function compared to the Acoelomata.

Since the **Coelomata** represent advanced triploblastica it is natural for them to differ widely from the **Coelenterata** (Diploblastica). It would therefore be worthwhile to jot down the major differences in the organization of these **two**:

Coelenterata	Coelomata
1. These are *diploblastic* animals and have two cell layers in their body: *ectoderm* and *endoderm*. True mesoderm is never found.	1. These are *triploblastic* animals and have three germinal layers in their embryos: *ectoderm*, *endoderm* and the intermediate *mesoderm*.
2. They stand at the tissue level of organization and do not have definite organs.	2. They are at the organ grade of organization and have definite organs specialised for different functions.
3. These animals have an internal cavity in which no separation between the digestive cavity and the body cavity exists. There is one single continuous space which is known as the *enteron* or *coelenteron* which opens to the exterior by a single opening, the *mouth*.	3. These animals possess a true body cavity or coelom which is separate from the digestive cavity. The coelom is the space between the alimentary canal and the body wall which is bounded by tissues of endomesodermal origin and is lined by peritoneum.
4. Radial symmetry is conspicuous.	4. Bilateral symmetry is conspicuous generally.
5. The mouth serves for the ingestion as well as egestion and there is *no anus*.	5. *Mouth* serves for ingestion and *anus* serves for egestion.
6. Nervous system is a nerve-net of cells. The nerve-cells lack polarity. The nervous system is thus of a very primitive type.	6. Nervous system is highly developed: brain and nerves are found and there is a distinct centralisation of the nervous system.
7. Respiratory, excretory and circulatory systems are not found.	7. These systems are found and attain varying complexity in different groups.
8. Only one phylum, the Coelenterata is included. Compared to Coelomata, their number is very small.	8. A number of phyla e. g. Annelida, Arthropoda, Mollusca, Echinodermata and Chordata are included. The large majority of animals, thus, are coelomate.

2

The Protoplasm and the Animal Cell

What is protoplasm? Describe its composition and explain its role in animal life.

Make a labelled sketch of an animal cell and discuss functions of its component parts.

Give an account of the structure of an animal cell and state the functions of its component parts.

Describe the structure and composition of protoplasm.

The animal body like that of plants is composed of a living aggregate of matter of complex physical and chemical constitution known as **protoplasm** (Gr. **protos**, first, **plasma**, form). Protoplasm is the living matter and is truly the physical basis of life. In other words, it is to this aggregate of matter that the animals owe their life and the complex series of phenomena through which life expresses itself. The protoplasm of an animal is organized into an infinite number of masses or units which have been by tradition referred to as *cells*. There are, however, animals whose entire body is made up of a single cell. Such animals are known as **Protozoa.**

We have stated that protoplasm is the physical or material basis of life. It is the essential substance responsible for all vital activities and is therefore found in all parts of the organism which are vital and active and where active changes concerned with life are going on. Protoplasm is an organized mixture of many substances of complex chemical constitution and is not any one particular chemical compound. Chemically it is not a single substance. It shows variations in different animals as well as the different parts of the same animal with regard to its physical and chemical organization and yet there are a number of properties or characteristics which the protoplasm of all living organisms shows universally. Like colloidal suspensions, protoplasm becomes coagulated by applying heat as well as by treating it chemically (by substances usually known as **fixatives** *e. g.* corrosive sublimate, formalin, potassium dichromate etc.).

It has been established that protoplasm is a **colloidal system** of a highly variable viscous consistency capable of changing from the 'sol' to the 'gel' condition,—the former being the more liquid condition than the latter. The solation and gelation are very well observed in Amoeba. All protoplasm is a fluid of viscous nature—it may be clear or may have minute granules when it is described as **granular.** Under microscope, protoplasm appears to consist of a liquid medium suspended in which are minute colloidal particles, globules, fluid droplets and vacuoles. It is a slimy, hyaline contractile substance and has been likened to an **emulsion** in its structure as a whole. Protoplasm is also found to be gelatinous sometimes.

Protoplasm is a highly complex colloidal system and behaves like a viscid liquid. It appears to be composed of a homogenous ground substance 'hyaloplasm' suspended in which are many granules known as 'microsomes'.

Butschli found that the protoplasm has a number of small closely packed vacuoles and he therefore considered protoplasm as a foam like structure. It has now been found that the protoplasmic viscosity varies in different kinds of cells and in different physiological conditions of the same cell. Protoplasm is observed under two conditions (1) when more fluid—the condition being known as 'sol' and (2) when it becomes more solid—assuming the 'gel' condition. When in liquid condition, the protoplasm exhibits movements within the cell—rapid trembling movements of particles. This is known as **Brownian movement** and is due to the bombardment of granules by the molecules of the fluid in which they are suspended. The smaller granules move more swiftly. The protoplasm contains various kinds of granules which are elaborated in it and which are made up of proteins, its most important constituents. The proteins have a high molecular weight and are composed of carbon, hydrogen, oxygen, nitrogen, sulphur and small quantities of phosphorus. We will return to the composition of protoplasm again.

The structure of protoplasm has been variously interpreted and conflicting views have been expressed as to its exact structure.

According to one view postulated by **Fromman** the protoplasm consists of a fine network of fibrillae or threads which intersect each other—the places of intersection being thicker and consequently appearing like granules. The spaces between the intersecting fibrillae are filled up with fluid, thus producing a sponge like structure. Since these observations are based upon stained materials it is quite likely that the results are chiefly due to artificial coagulation.

According to the second view expressed by **Butschli,** the protoplasm is a honey-comb like structure of the nature of a network comparable to a frothy emulsion of oil. He described the structure of protoplasm as **alveolar.**

According to the third view by **Flemming** the protoplasm contains threads and an interstitial substance. The threads are parallel in arrangement and the granular structure is produced due to their meeting at certain places.

The fourth view due to **Altmann** is known as the granular theory and it considers protoplasm to consist of a number of minute granules surrounded by a liquid substance. Modifications in the structure of protoplasm are due to concentration or isolation of these granules. They may be situated closely near each other and may unite to form rows or thread like structures. Granules are the elementary structures according to this view and they arise by growth or by division of the pre-existing ones. The protoplasm consists of colonies of granules known as bioblasts.

There is in fact no established opinion about the exact structure of the protoplasm in view of the difficulty of observing it in natural condition (without fixation) by ordinary methods. Even by the use of *ultra-violet* light no essential microscopic structure could be established. This leads us to conclude that "protoplasm is a complex colloidal system with a complex ultra-microscopic structure—no essential structure being visible under the microscope."

Composition of Protoplasm

Approximately 75 to 85 per cent by weight of protoplasm is water. The dry residue consists largely of **proteins** (complex nitrogenous compounds of carbon, hydrogen, oxygen, nitrogen, sulphur and traces of phosphorus sometimes which are easily hydrolysed into mixtures of amino-acids) **carbohydrates** (*e. g.* glycogen, sugar), **fats** and **oils** and **salts** are also present in protoplasm. Sulphur, iron, phosphorus and chlorine etc. and sodium, potassium, magnesium and calcium are also present and are essential constituents. Many substances which are not essential constituents of the living protoplasm,—in other words non-living substances are also almost invariably found in the dry substance of the protoplasm. These are, for example excretory substances and reserve food materials. It may be stated that besides 75 per cent of water (by weight)—the rest of the constituents of protoplasm largely consist of proteins; proteins may roughly form about 45 per cent by weight of the entire dry substance; carbohydrates and lipoids form 25 per cent each and the rest of the 5 per cent includes all other substances.

A characteristic feature of the protoplasm is the presence in it of special kind of catalysts known as **enzymes** which are chemically proteins and are also colloidal in nature.

Role of protoplasm in animal life

We have already stated that protoplasm is the very life of a living body. No life or vital activity is possible in its absence. Vital activities include growth, development nutrition, reproduction and irritability or response to stimuli, locomotion and spontaneous movements etc. Complex physico-chemical reactions: both of the nature of break-down of complex chemical compounds into more simple ones, and the building up of more complex compounds from the simple ones, are always going on inside the protoplasm itself, at the ordinary temperature. All such reactions are collectively spoken of as **metabolism.** The building up reactions are known as **anabolism** and the breaking down reactions are known as **katabolism.** Metabolism is possible only as far as the protoplasm is maintained in a living state. The protoplasm is capable of maintaining its own composition regardless of the medium that surrounds it. This is due to the surface membrane of protoplasm which can separate two solutions of dissolved substances although they may be at different concentrations. This semi-permeability of the surface-membrane of protoplasm lasts only as far as it is living. We cannot discuss here detailed properties of the surface membrane of protoplasm. Suffices to state that the *protoplasm is the sole cause of animal's life.*

The Cell

The term **cell** was first introduced in biology in 1665 by Robert Hooke in connection with the cells of cork which appeared like closed chambers completely separated from each other. Literally the word 'cell' means a small room or compartment. The term was originally used for the plants in which these closed compartments or chambers are distinctly separated from each other by hard and thick cellulose walls. The term has since been in use for the animals also, although in their case the walls separating the various cells (**intercellular walls**) are mostly thin and much less conspicuous than plants. The term is now in universal use and is also applied to the protozoa whose entire body is made up of a single cell. The cell has been defined as **a small corpuscle of protoplasm containing a specialised component structure called nucleus.** It is a unit into which the protoplasm of animals is usually organised although it is in itself a complicated structure containing nucleus and many other components. Amongst animals the term cell implies the full contents of the chamber—*i. e.* every structure inside it. The red blood corpuscles of mammals which are without nucleus are considered as degenerate cells. The striped muscle of vertebrates is formed of cells with many nuclei; some consider them as single cells while others regard them as multicellular structures in which cell-walls are absent forming **syncytial** masses of protoplasm (a tissue without distinguishable cell-walls is known as a **syncytium**). The cell-substance as a whole including the nucleus is known as **protoplasm**. The substance of the nucleus is known as **nucleoplasm** or **karyoplasm** and the substance of the cell excluding nucleus is known as **cytoplasm.**

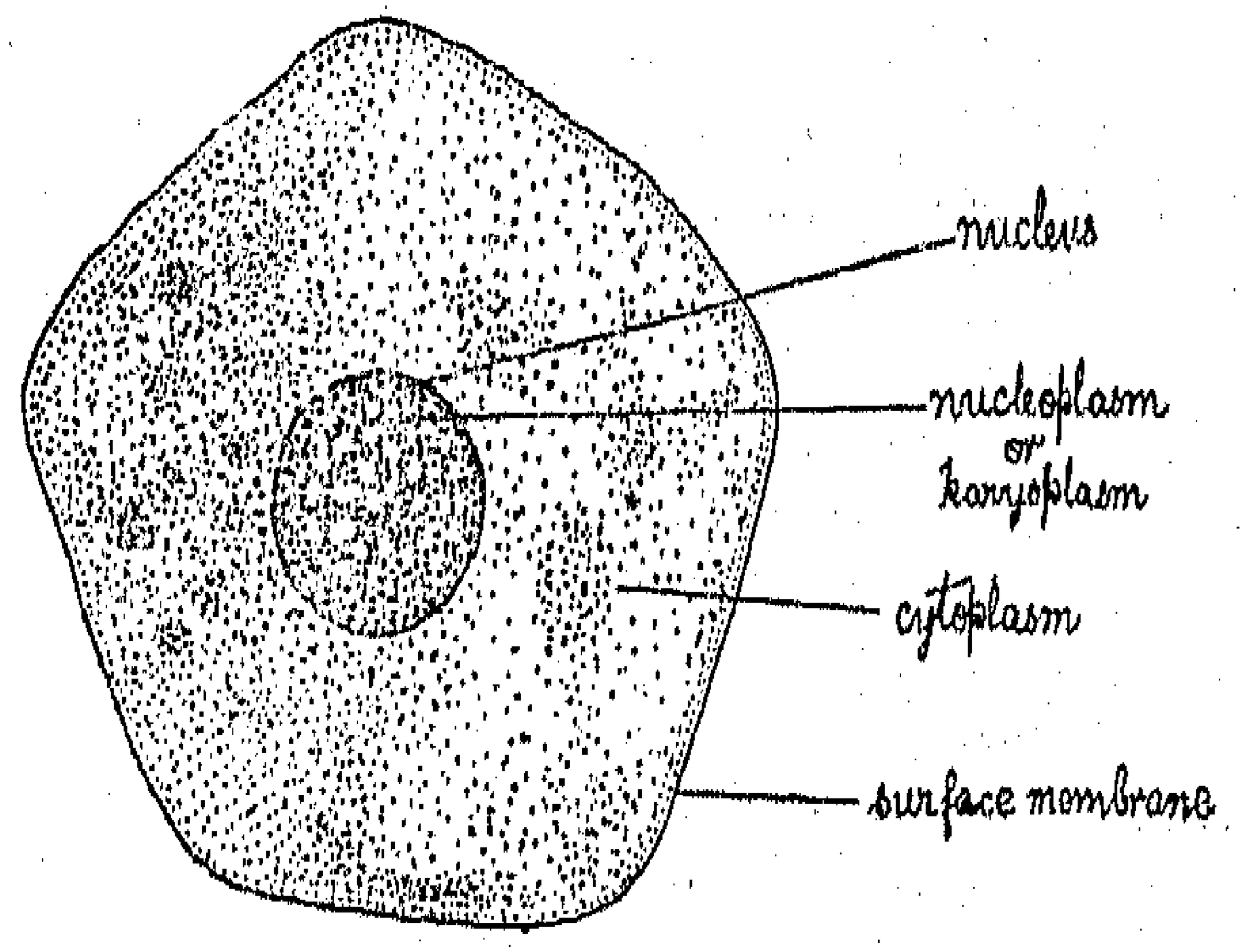


Fig. 1. An animal cell showing the cytoplasm and karyoplasm.

The animal cell is usually bounded by a thin surface layer known as **surface membrane or plasma membrane** which is made up of a thin peripheral protoplasmic film of a different consistency (than the rest of the cytoplasm)—usually more viscous and often gelatinous. The plasma membrane may also be surrounded by a nonprotoplasmic wall. The plasma membrane plays a very important role in regulation of changes between the cell and the environment. The gelatinous surface layer as well as the external non-protoplasmic wall give shape to the cell. Amongst animals the plasma membranes are traversed by fine strands of protoplasm which connect various cells and maintain continuity between them. These thread like protoplasmic connections are known as **plasma bridges** or **plasmodesms.**

Cytoplasm is a clear, hyaline and homogeneous fluid containing various granules and substances.

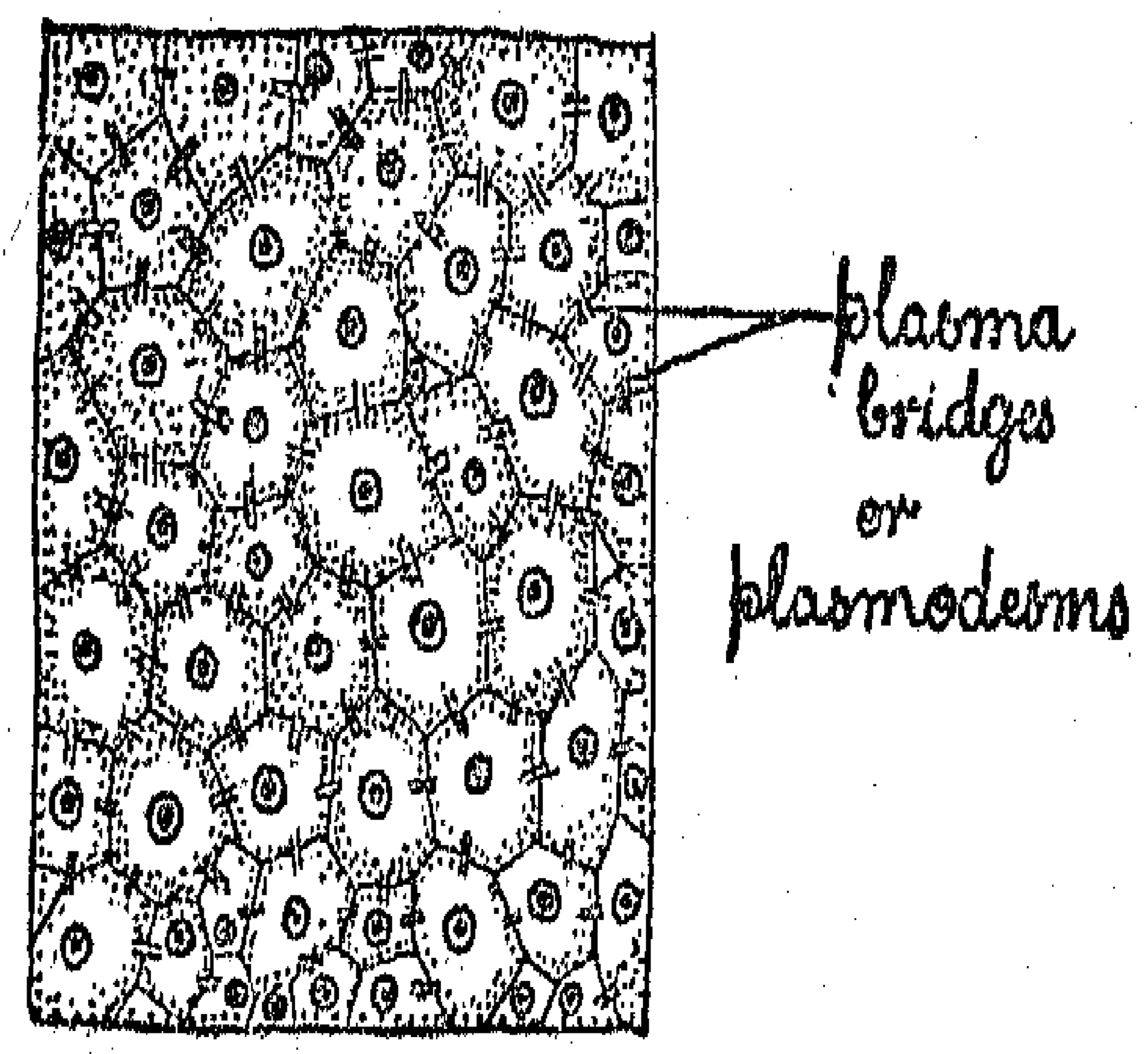


Fig. 2. Plasmodesms shown digrammatically.

There are three kinds of substances or cell-components:

1. **Protoplasmatic.**—These substances are active and have power of growth and perpetuation.

2. **Alloplasmatic.**—These are not capable of perpetuation although they perform active functions. They are products of differentiation of protoplasm but are incapable of reproducing themselves. Cilia, flagella and spindle fibres belong to this category.

3. **Metaplastic.**—These are lifeless and neither reproduce nor discharge active functions. They are secondary products of differentiation and include various inclusions like starch, fat globules and intercellular substances.

We will now discuss the cytoplasmic organs of a typical animal cell.

Mention has already been made of the (1) **surface membrane,** (2) another kind of cytoplasmic bodies are **mitochondria.** The mitochondria are small bodies in the form of rods, granules, threads and sometimes spheres. They may undergo changes of form *e. g.* rods may change into granules, granules into threads and threads into rods. They are found scattered through, or may be collected into clusters or may be particularly abundant in some part of the cytoplasm and may be rare or less numerous in other parts. They are aggregated in a large number at places where active metabolism is going on. The mitochondria are found in almost all animal cells (except in the degenerate cells like red blood corpuscles of mammals). They are made up of a central core of protein and a lipoid cortex. They grow in length and divide transversely. They secrete some products of protoplasmic activity *e. g.* yolk. They also play an important role in the elaboration of secretion granules. These bodies exhibit active movements during life of the cell; they wriggle about or twist to and fro and often move from one part of the cell to another.

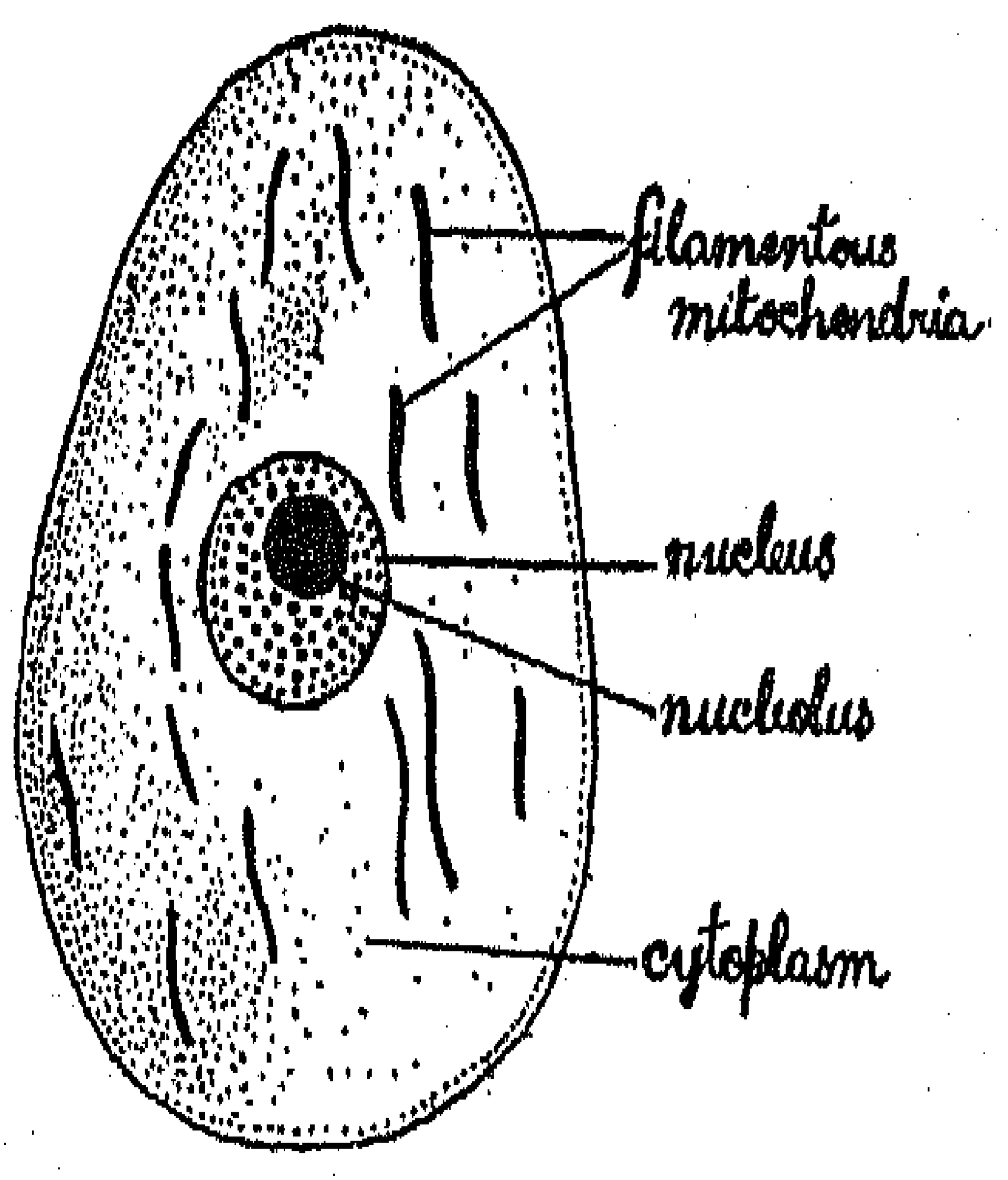


Fig. 3. A cell showing filamentous mitochondria.

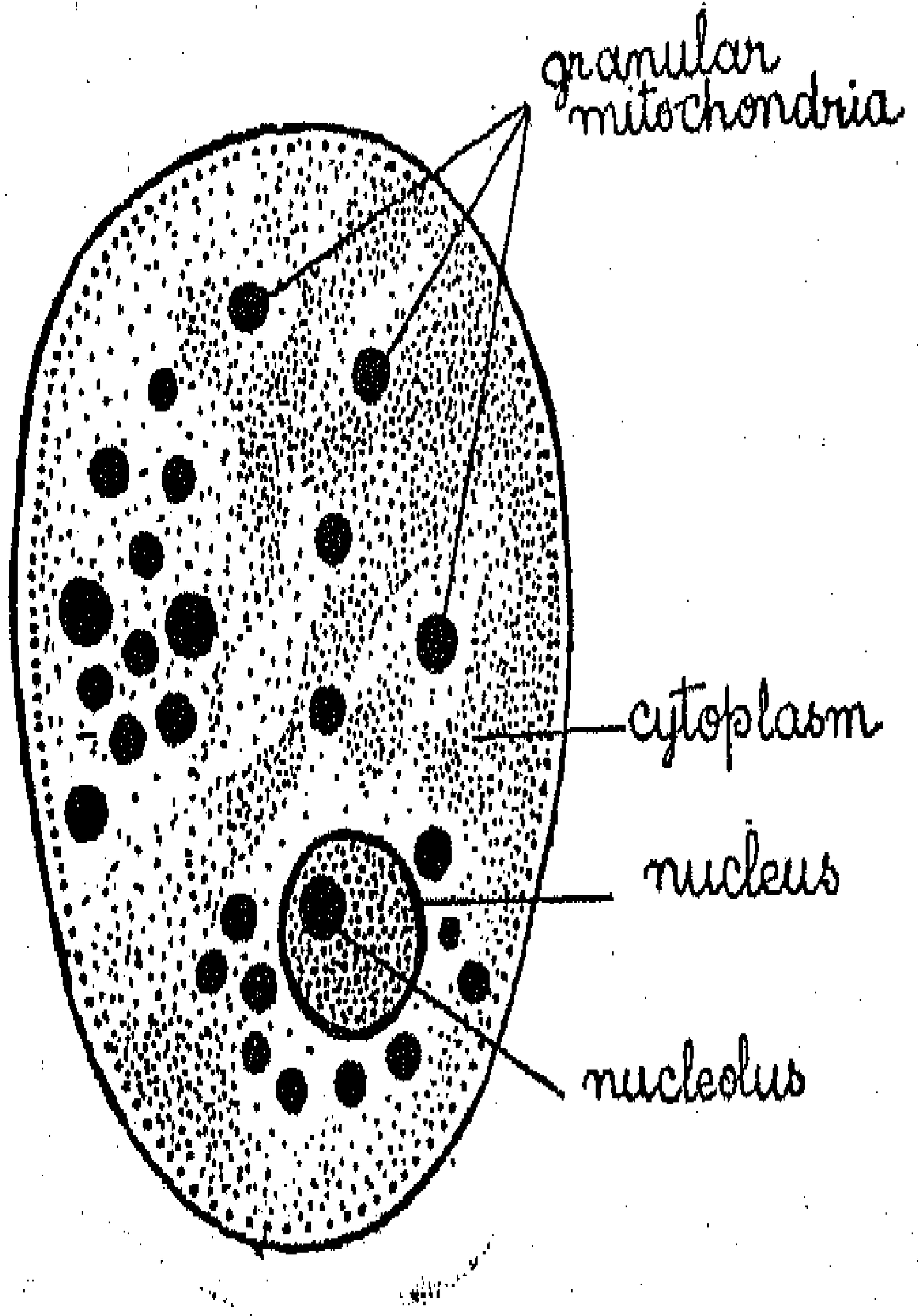


Fig. 4. A cell showing granular mitochondria.

It is believed that through enzymatic activity at their surface the mitochondria play an important role in the formation of secretions. They are also believed to be responsible for yolk-formation. They are responsible for general metabolic activity of the cell. Mitochondria were first described in germcells giving rise to spermatozoa and later on their universal occurrence was discovered. They have a hand in the physiology of spermatozoa and form the sheath of the axial filament of the middle-piece of the sperm. They are also found in protozoa in which they are responsible for enzymatic and synthetic activities. The granular mitochondria are called **chondriosomes,** the rod or thread like mitochondria are called **chondrioconts** and the spherical ones are known as **chondriospheres.** The mitochondria do not have nucleoproteins and are therefore not nuclear in origin. (3) **Golgi bodies.**—These were first discovered by **Golgi** in 1898 and hence have been known as 'Golgi bodies' after the name of the discoverer. They are found in all animal cells except the degenerate ones and are of the form of tubes or spheres variously arranged—sometimes scattered throughout the cytoplasm and sometimes occurring in localised clumps between the nuclear membrane (near it) and the chemically very active centres of the cell. They are usually found somewhere in the neighbourhood of nucleus. The Golgi material consists of a system of rods and often looks like a network which is made up of individual elements which really do not form a network but look like that because of their closely clumped location. This material exhibits movements in a living cell– sometimes scattering and diffusing throughout the cytoplasm and then again coming close to each other. Their movements are considered to be related with the activity of the cell. The Golgi bodies are made up of protein and lipoid substances and consist of an inner part and an outer cortical part.

Treated with osmic acid, the Golgi apparatus becomes black; when treated with acetic acid it disappears. It is best demonstrated with reagents without acetic acid and then impregnated with silver. The Golgi apparatus is not a structure with permanent form. The form and disposition is subject to changes correlated with the activity of a cell or its various stages. The material can grow and multiply and is therefore a living component (protoplasmic) of the cell. It has been observed that the form and distribution of Golgi material change and these changes are correlated with the secretory activity of cell. It is therefore assumed that it plays an important role in the secretory activities. The Golgi material of gland cells (*e. g.*, pancreatic cells) is concerned with specific secretory processes because when activity of the gland commences, the Golgi material is considerably enlarged. According to **Duthie** the Golgi material exerts further modifying influence on, and brings about changes in the secretion granules already originated and elaborated by mitochondria. According to **Kirkman** the Golgi substances concentrate the materials already elaborated by the cytoplasm and they act as **condensing membranes.** According to **Subramanian** the Golgi apparatus has a role in the elaboration of intracellular enzymes. In the midst of conflicting views regarding the exact function of the Golgi bodies it can be stated that they certainly have some active function connected with the elaboration of secretion granules which are possibly synthesised by the production of enzymes.

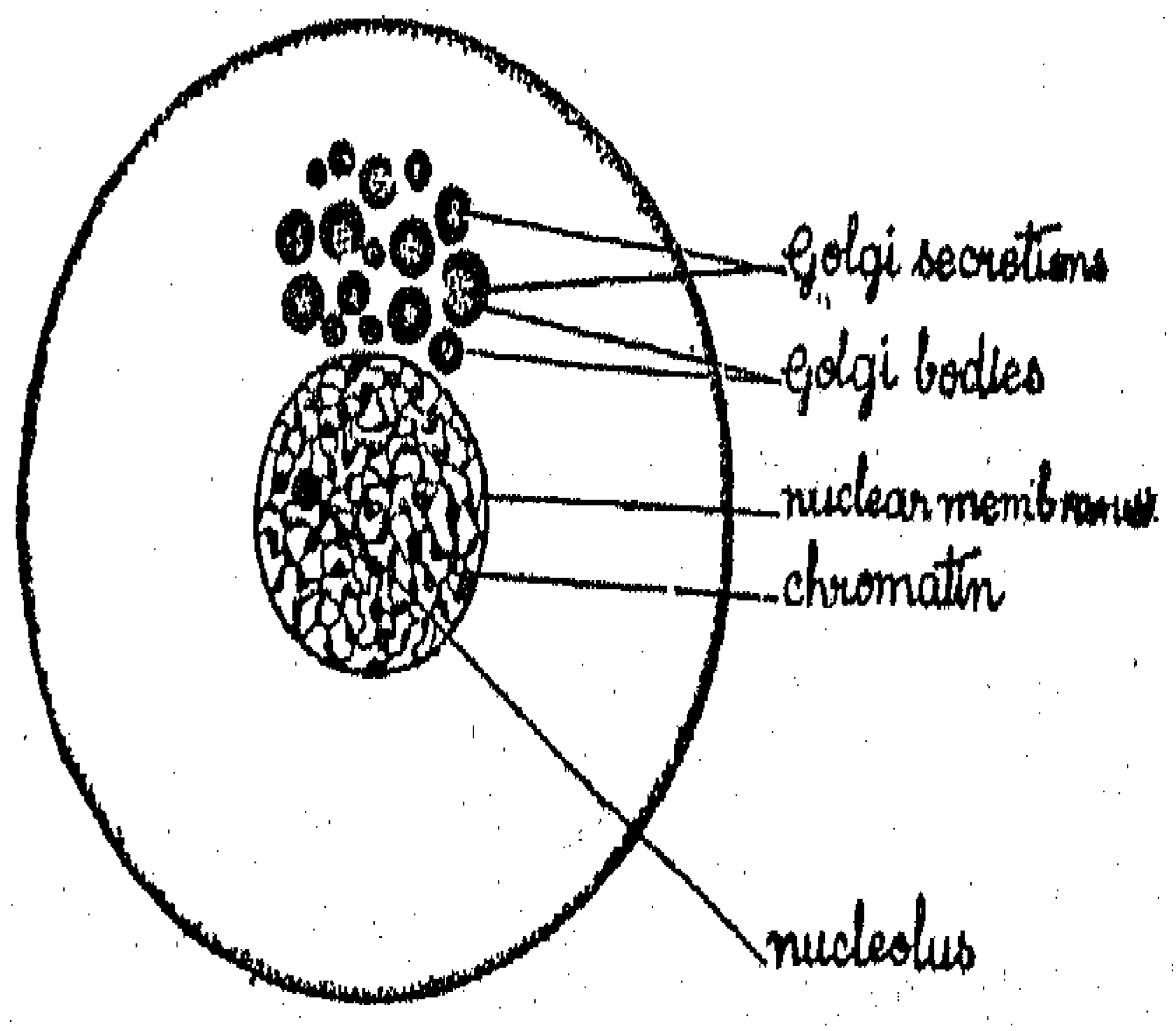


Fig. 5. Diagram to show active Golgi bodies (From various sources).

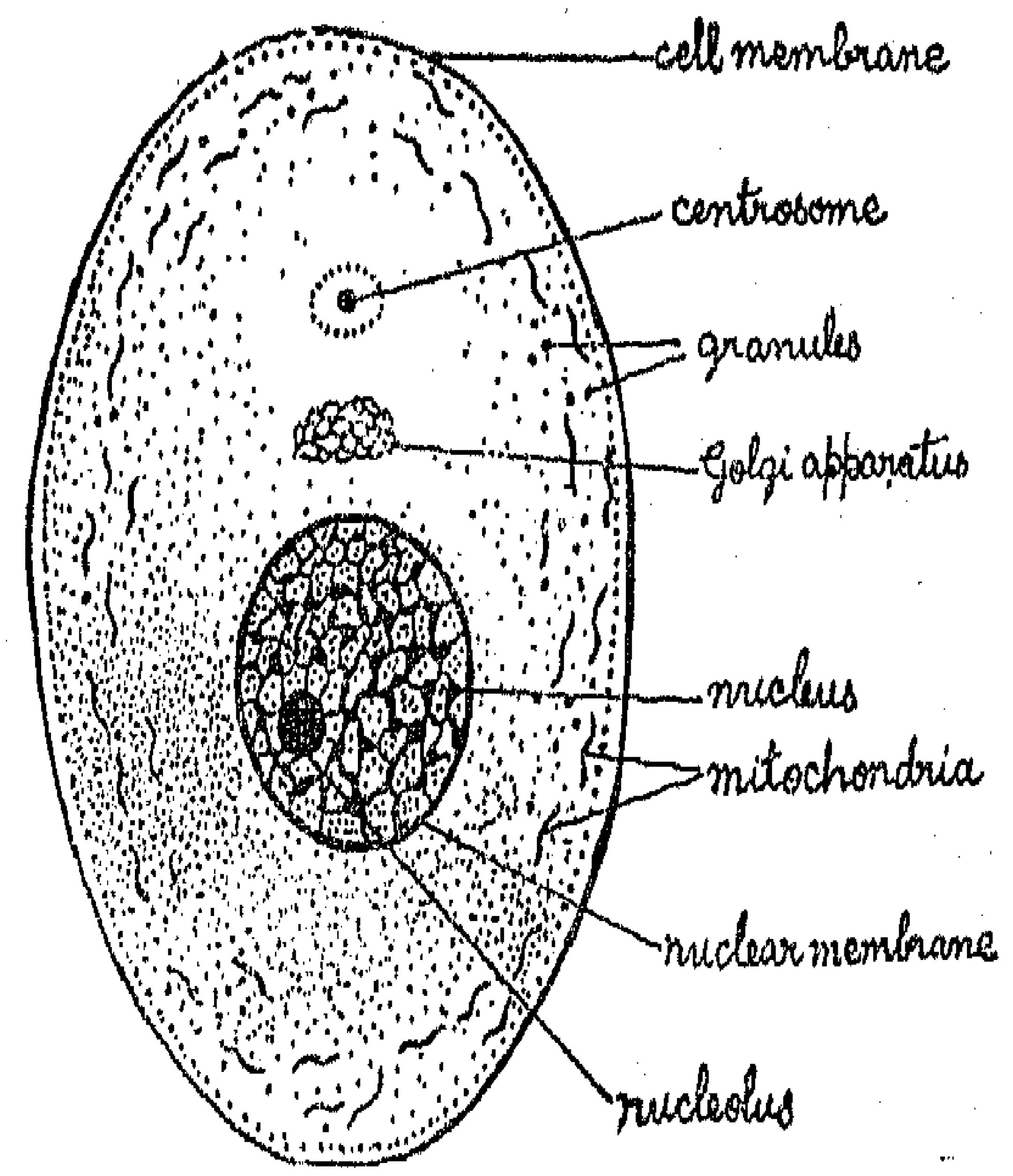


Fig. 6. Diagram of a cell showing essential structures (From various sources).

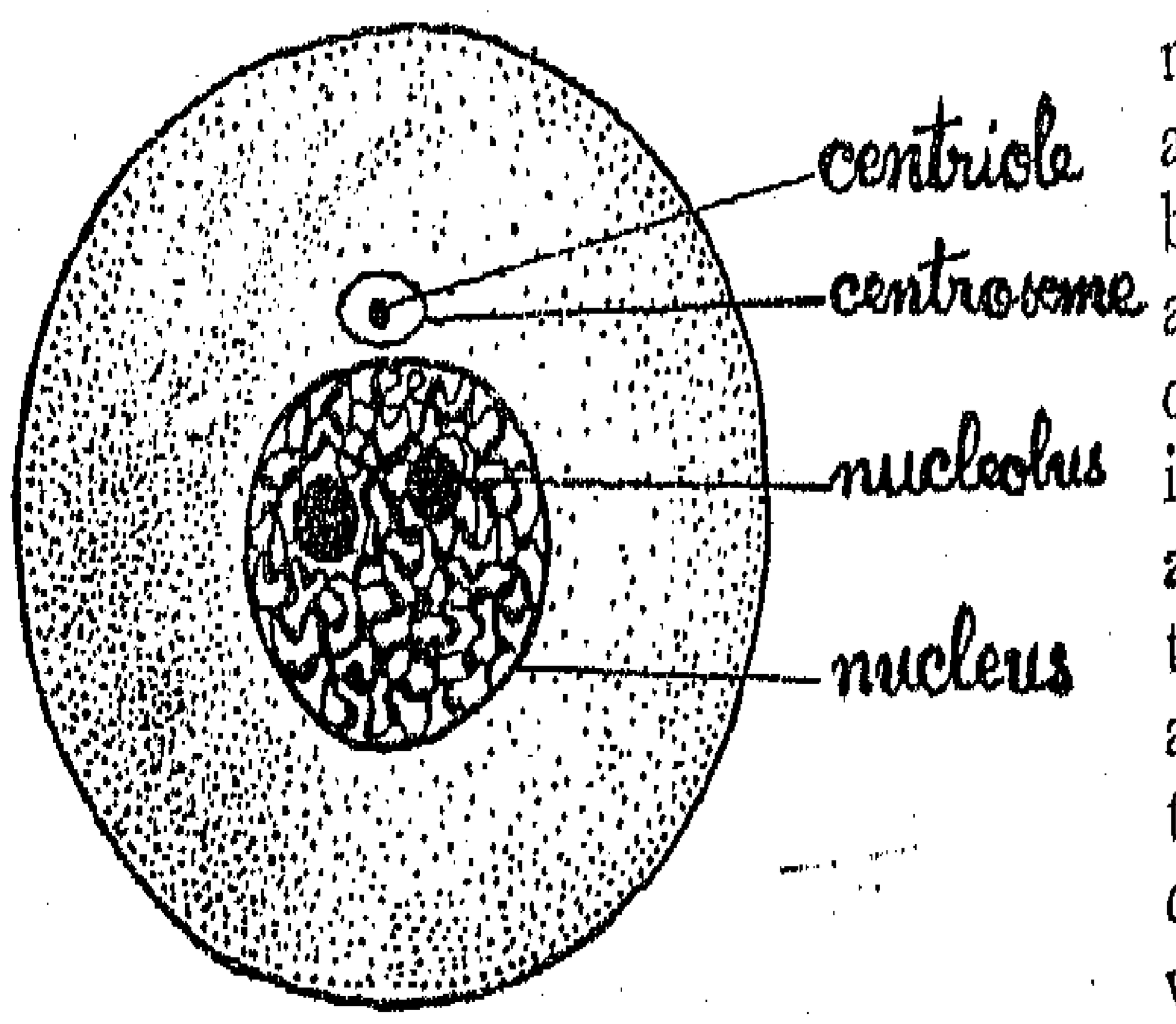


Fig. 7. Resting cell to show the centrosome and the centriole.

The **centriole** and the **centrosome**--During the mitotic division of cell, asters arise from central bodies. The central body associated with certain other complex structures is known as the **central apparatus.** In its centre there is a granule known as **centriole.** The centriole is surrounded by a cytoplasmic investment of varying complexity; when this cytoplasmic investment is small, it is known as **centrosome** and when large it is known as **centrosphere.** A region of modified cytoplasm surrounding the centrosome is known as **archoplasm.** The centrosomes are cytoplasmic bodies growing out from the centrioles. In the primitive protozoa (many flagellates) the centrosome is found inside the nucleus. The centrosomes give rise to the basal granules of cilia which control their constant beat. During the early prophase of the mitotic division of the cell the centriole and the centrosome divide and the resulting two centrosomes move apart. The astral rays appear in the cytoplasm around each centrosome after which the central spindle makes its appearance. The centrosomes finally come to lie very close to the opposite poles of the nucleus. Thus the **centrosomes are the controlling centres of kinetic activities during cell-division.** The centrosomes are thus a dynamic centre of the cell.

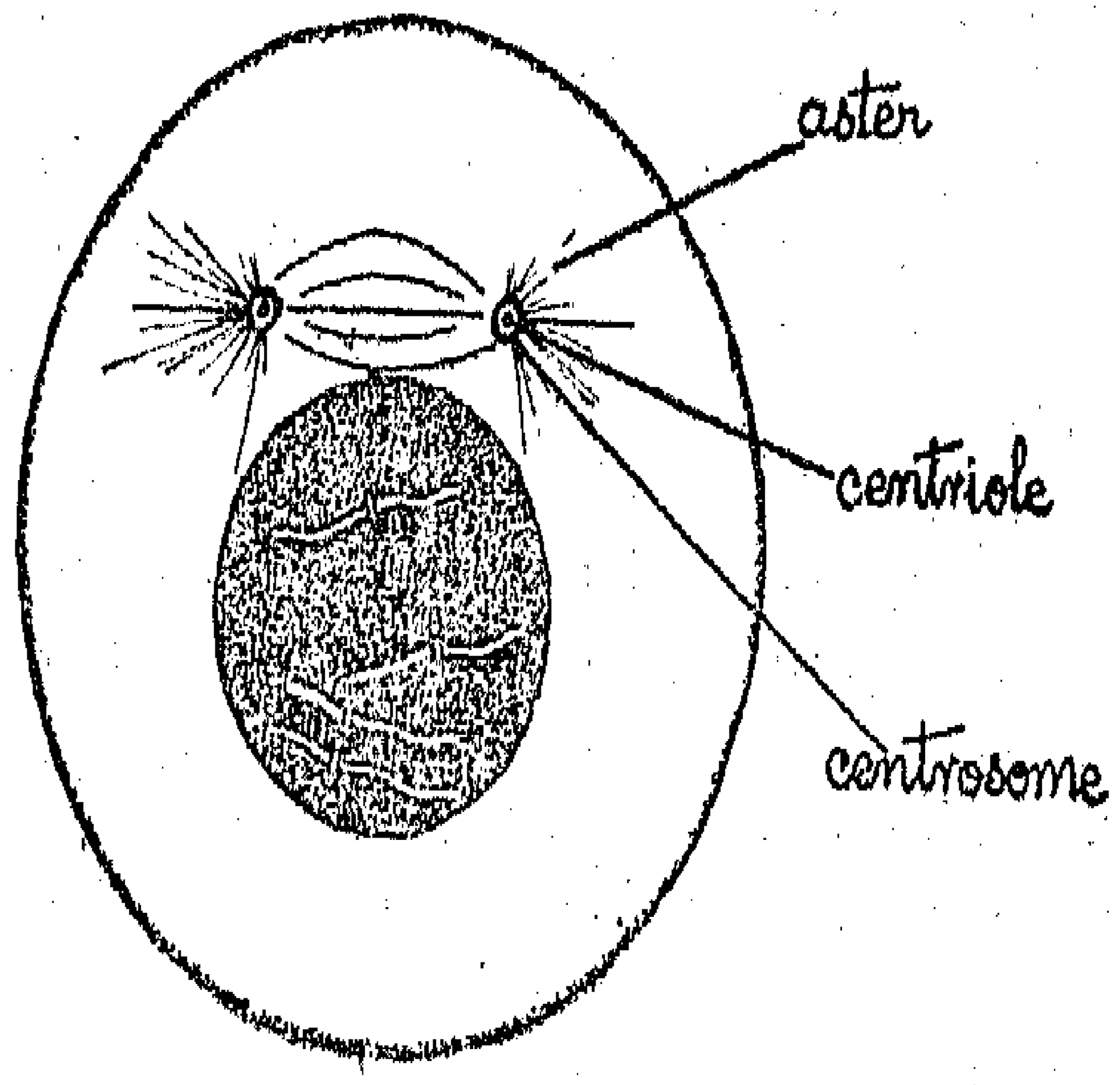


Fig. 8. First initiation of nuclear division accompanied by the division of the centriole and the centrosome.

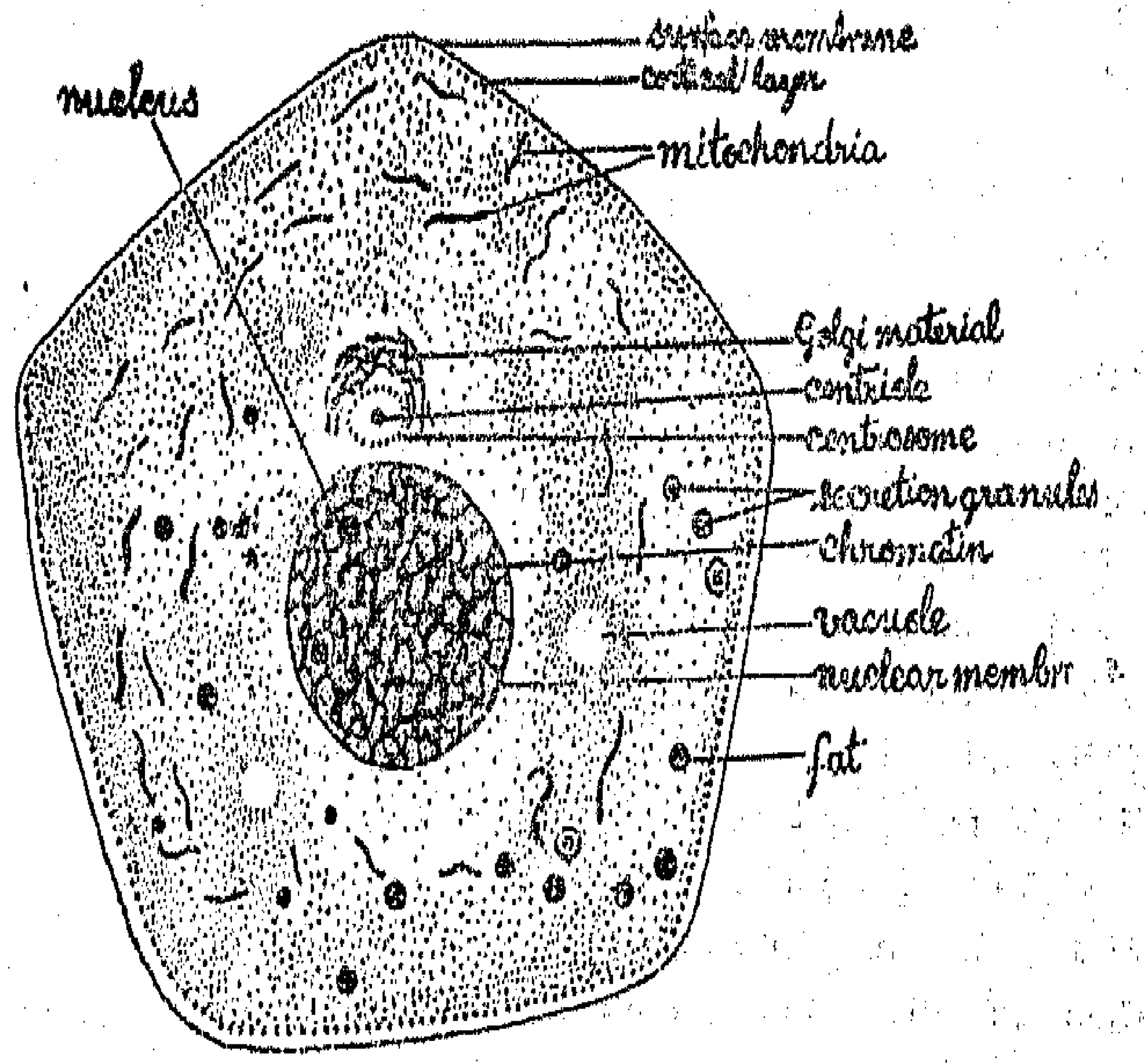


Fig. 9. A diagram to show various structures in a cell.

The **Nucleus**—All animal cells capable of survival and multiplication possess a rounded body in the interior of the protoplasm known as **nucleus.** The complex protoplasmic material of nucleus is known as **chromatin.** The nucleus is separated off from the surrounding cytoplasm by a thin and solid limiting membrane known as **nuclear membrane.** The protoplasm of the nucleus is known as **nucleoplasm** and the chemical substances constituting it are the **nucleoproteins** which are readily stained by **haemotoxylin.** Within the nuclear membrane there is a complex network of threads or fine fibrillae formed of a substance know as **linin.** This complex network of linin is known as **achromatic network** and it does not stain with basic dyes. It can be stained readily with acidic dyes. The basichromatin (chromatin stainable by basic dyes) is in the form of granules distributed all along achromatin and has a reticular structure. The homogeneous ground substance of the nucleus is called nuclear sap. Nuclei of higher animal-cells have one, two or sometimes more prominent rounded bodies known as **nucleoli.** Nucleoli are formed of a substance known as **plastin.** The staining properties of nucleolus differ from chromatin and it contains nucleic acid which differs from that of chromatin. The nucleolus is a centre of storage or elaboration of substances like linin. It supplies material for formation of spindle fibres and is concerned with secretory processes of cell giving rise to structures like yolk-spheres. **Hegben** showed that in cockroach nucleolus becomes vacuolated and portions from it become excluded which are scattered and subsequently passed out through the nuclear membrane into the cytoplasm. Thus the nucleoli may be concerned with the exchange of metabolic material between the nucleus and the cytoplasm. Many animal-cells are without nucleoli.

The nucleus has been assigned many functions. It plays an essential role in cell-division (or reproduction). It it responsible for the division of cell into two equal parts. Nucleus plays an important part in fertilization and carries hereditary qualities of the two parents thus being a vehicle of hereditary characters. Nucleus is the main architect of form, character and activities of a cell. If an amoeba is cut into two pieces, digestion occurs only in the part containing the nucleus. The part without nucleus dies in course of time. The enucleated part of amoeba has no faculties of regeneration, growth, reproduction or digestion. It lacks all natural powers. Nucleus is very necessary for secretion of cell-wall. In the root hairs of Marcantia nucleated masses produce cell-walls and the non-nucleated ones die. In certain cases *e. g.* Paramoecium the nucleus occurs in two parts—one is concerned with reproduction and the other one is concerned with metabolism of the body. The possession of two dissimilar nuclei as found in Euciliata and Suctoria amongst the protozoa is spoken of as the **nuclear dimorphism.** In the nuclei of many protozoa there are found spherical masses of nucleoproteins known as **endosomes.** The chromosomes do persist even in the resting stage of nucleus but it is difficult to make them out except during cell division.

Chromidia are spherical and small granules of nuclear origin made up of chromatin occurring in certain protozoa. They are found scattered through the protoplasm. Their staining properties are like those of basichromatin and it was thought (Hertwig) that they could form a nucleus by their aggregation.

Secretory granules are purely transitional structures derived from the mitochondria. They disintegrate and produce enzymes. They are found in cytoplasm.

Storage granules may occur in the form of starch, fat globules etc.

Plastids are found in some protozoa (but mostly in plant cells. They are granular bodies—synthetic in function and elaborate substances like chlorophyll.

Vacuoles are small cavities in protoplasm which may contain fluid material.

3

Cell Division

Describe the mitotic type of cell division and point out the differences from the meiotic type of cell division.

Describe the Mitotic type of cell division and state how it differs from the Meiotic type of cell division.

Describe the succession of events in Meiosis according to recent views.

Describe the Meiotic type of cell division. In what essential features does this differ from the Mitotic type of cell division.

In every case when a cell divides it is preceded by a nuclear division which may occur in three different manners:

1. **Mitosis**—(Karyokineses) or the **Indirect Nuclear Division.**
2. **Amitosis** or the **Direct Nuclear Division.**
3. **Meiosis** or the **Reduction Division** which occurs only during maturation of the germ cells. The division of the cytoplasm is known as the **cytokinesis** while the division of the nucleus is known as **karyokinesis.** Karyokinesis precedes cytokinesis.

The term **Mitosis** is applied to the remarkable series of complicated changes which the nuclear contents undergo during the division of the cell. The process is also known as **indirect nuclear division.** Mitosis is the usual method of division of nucleus and commonly occurs in the cells of the multicellular body. The process is more or less constant and the successive stages appear in the same order wherever it occurs. The speed and duration of the mitotic cycle varies with temperature, general conditions and the type of cell or tissue. It may take several minutes to several hours for a cell to divide. The entire process occurs in four main stages known as **prophase, metaphase, anaphase** and **telophase.**

1. Prophase—The centrosome becomes prominent. The centriole (minute deeply staining granule) and then the centrosome divides to form two centrosomes which move apart and finally occupy a position very near the opposite poles of the nucleus. Fine protoplasmic fibres forming the **astral rays** make their appearance in the cytoplasm around each centrosome. A central spindle shaped bundle of fine protoplasmic fibrils becomes visible and extends between the two centrosomes. Thread like chromosomes made up of chromatin material become visible. The chro-

mosomes make their appearance as a gradually thickening spireme which is a continuous structure inside the nucleus. The spireme is a closely interwoven mass formed of the linin network with its chromatin granules. The spireme is probably a single continuous slender thread consisting of very long chromosomes which cannot be observed as separate threads in early stages. Soon the continuous thread like spireme breaks up into pieces known as **chromosomes** which at first thin and elongate become shortened and thickened. The chromosomes are gelatinous bodies looking like looped threads and are composed of a linear series of minute bodies known as **chromomeres** arranged on a thread like structure. The chromosomes are longitudinally double at the prophase. They have splitted longitudinally for ultimate separation of the daughter halves. The two longitudinal halves of a chromosome are known as **chromatids.** The astral rays elongate, the nucleoli disappear, the nuclear membrane breaks down suddenly and the chromosomes become attached to the fibres of the spindle at a place in the chromosome known as the **centromere** which is an achromatic part. The chromosomes at this stage are longitudinally double but the chromatids lie very close to each other. The prophase stage can be summarised as *division of centriole into two each moving to the opposite poles of the nucleus, formation of the centrosomes and asters, growth of astral rays, appearance of spireme, its subsequent division into chromosomes which become longitudinally double, disintegration of the nuclear membrane and formation of the complete spindle consisting of fibres with which the chromosomes become attached in the region of chromomeres.*

2. Metaphase—The longitudinally divided chromosomes collect together on the equatorial plane of the spindle in a regular manner and in a single group known as **equatorial plate.** Sometimes these chromosomes are arranged in a ring round the equator and sometimes they are found inside the spindle. Each of the daughter chromosomes becomes attached to the opposite poles of the spindle by means of a half spindle element.

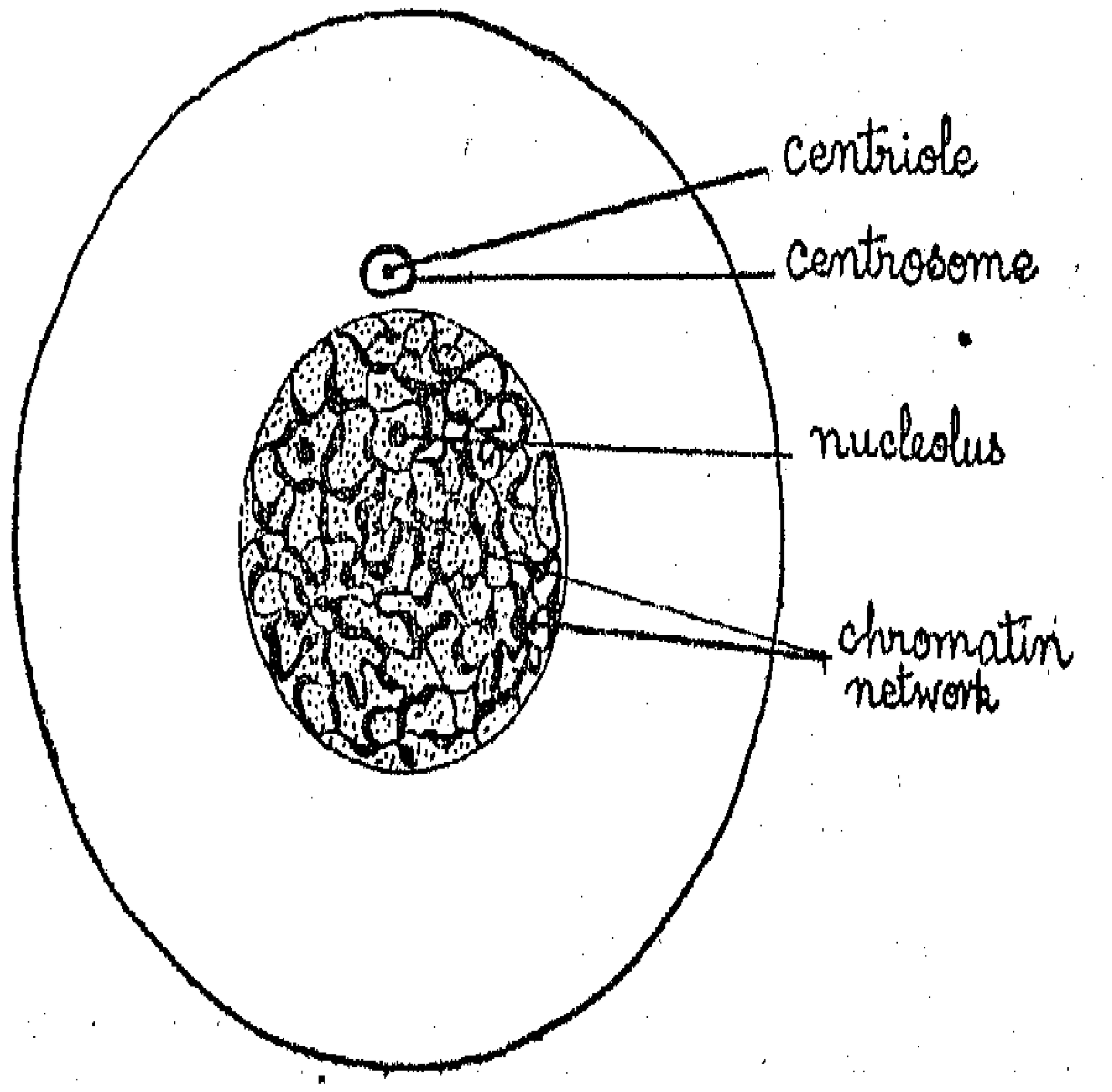
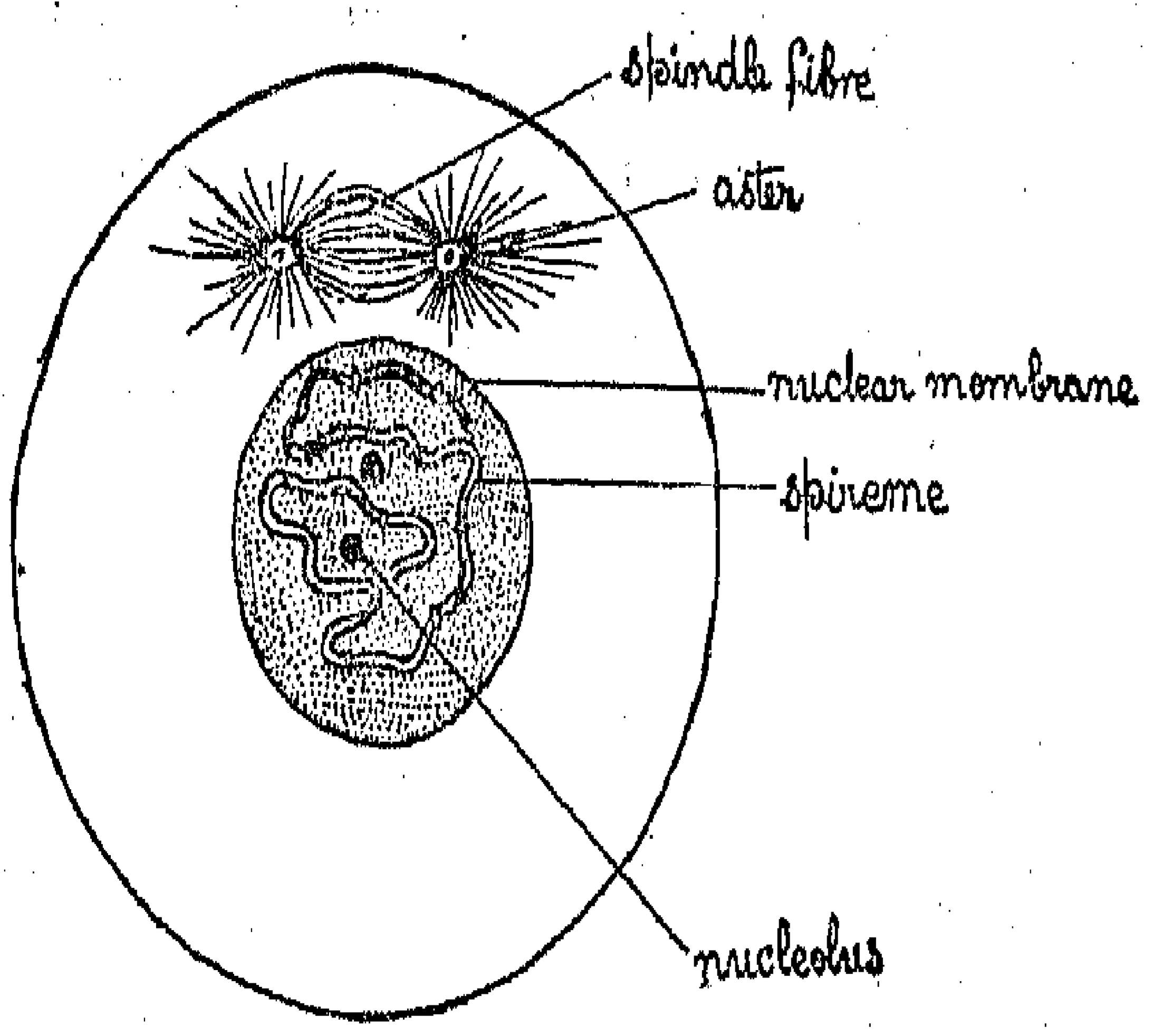
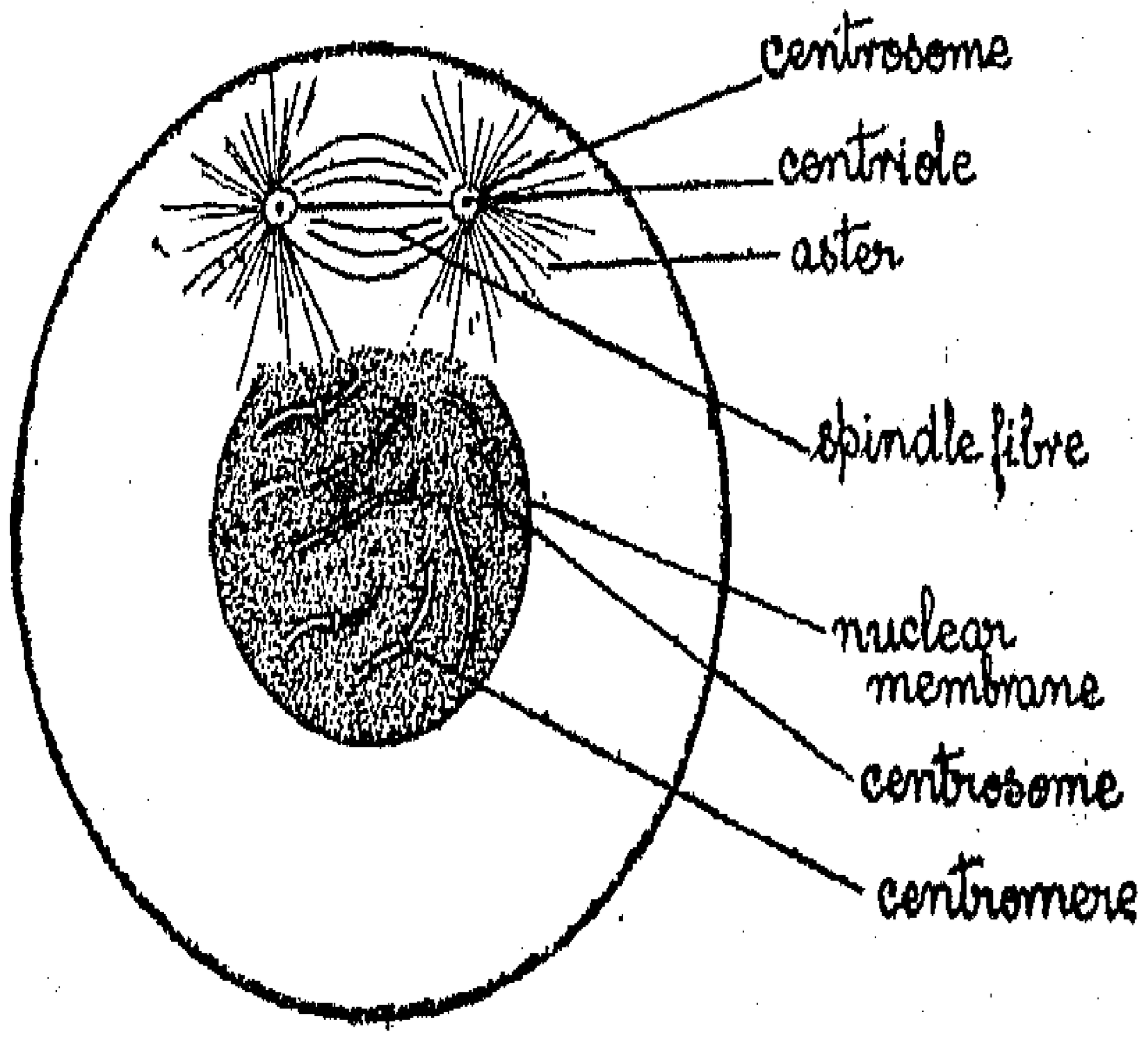


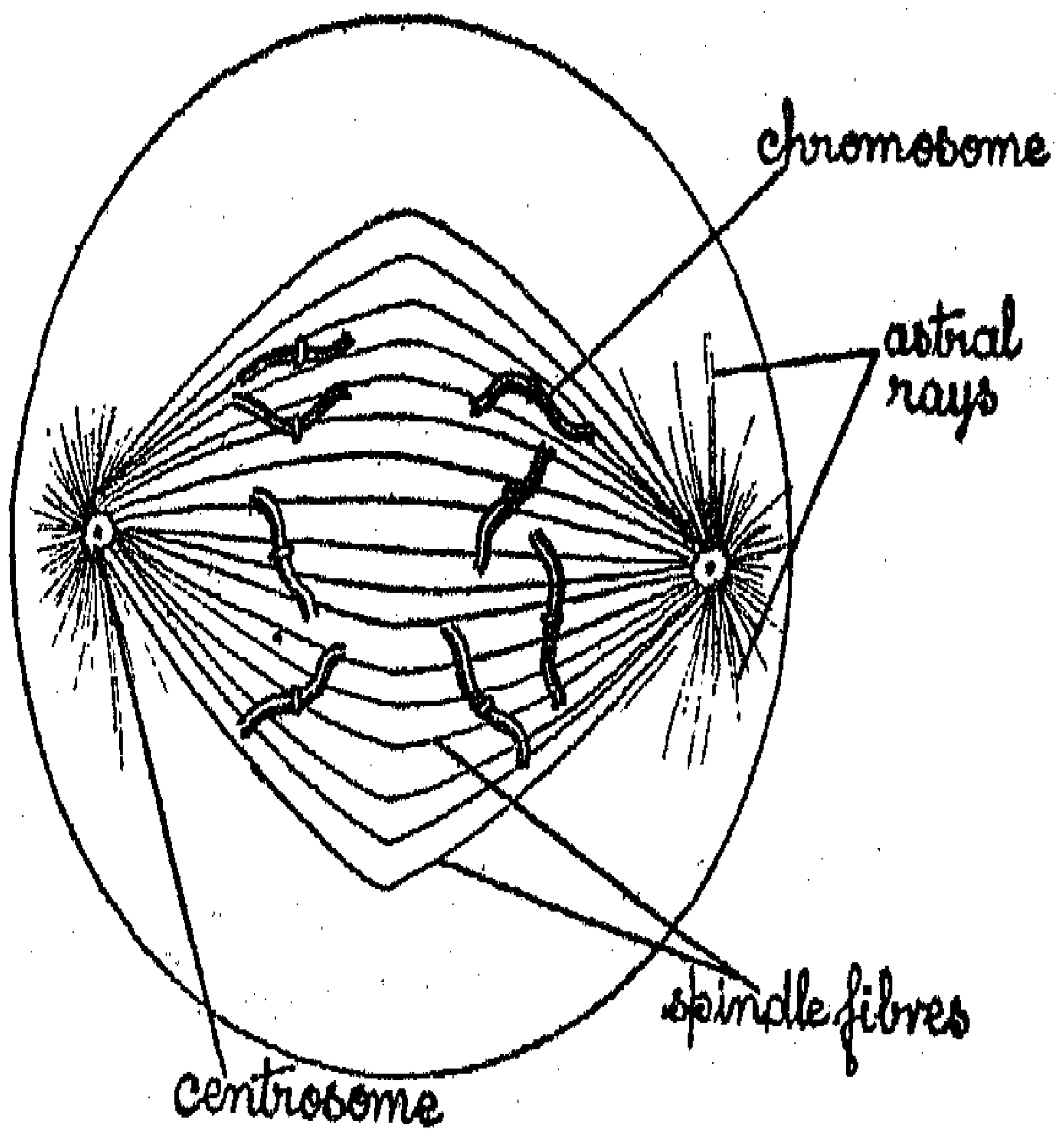
Fig. 10. Net-like chromatin and a single centriole.



PROPHASE (a)
Fig. 11. Centrosome divides and gets surrounded by asters—chromatin assumes spireme form.

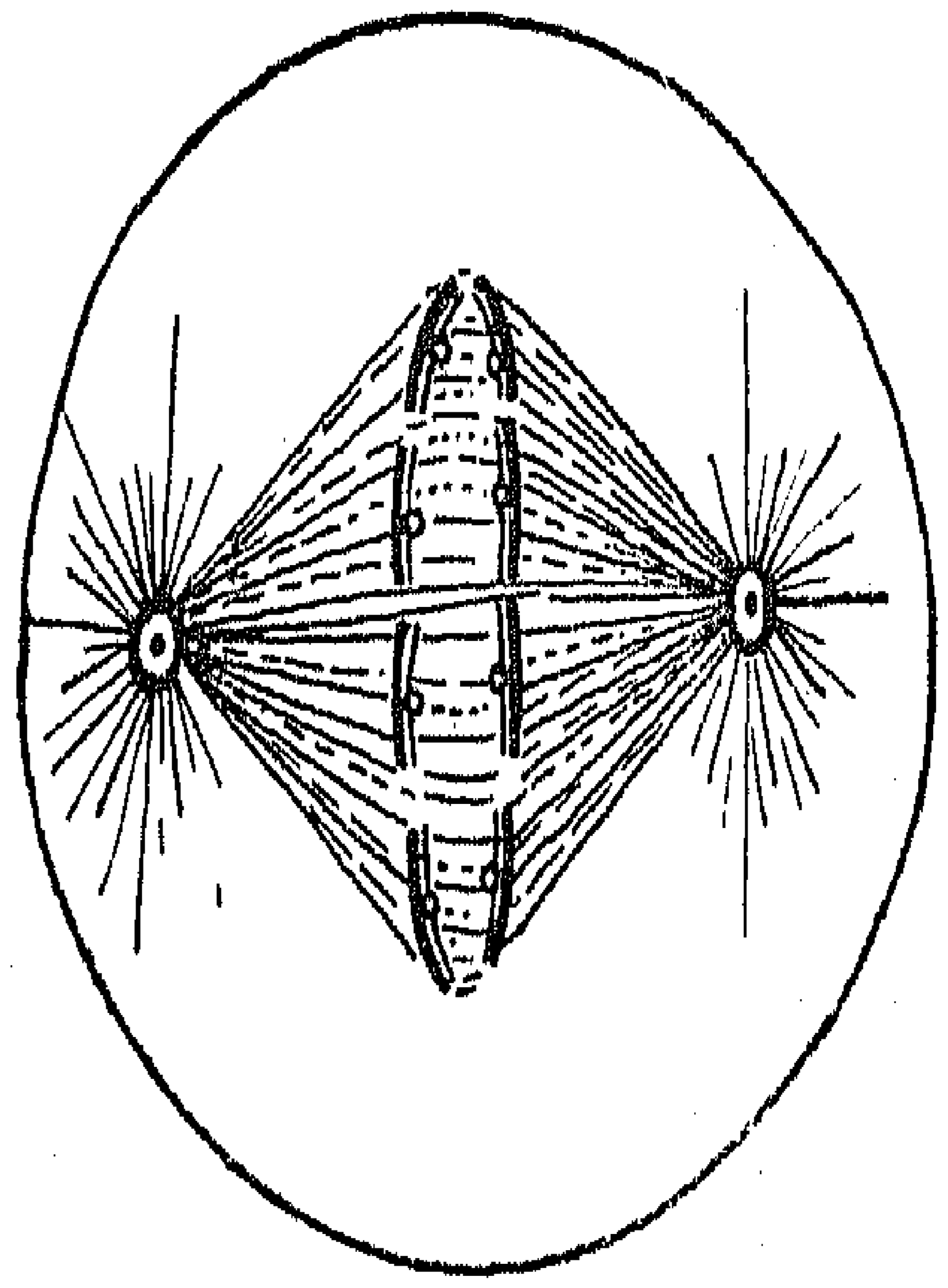
PROPHASE (b)
Fig. 12. Nuclear membrane breaks down, spireme divides into separate omes, chromos nucleoli disappear.





LATE PROPHASE

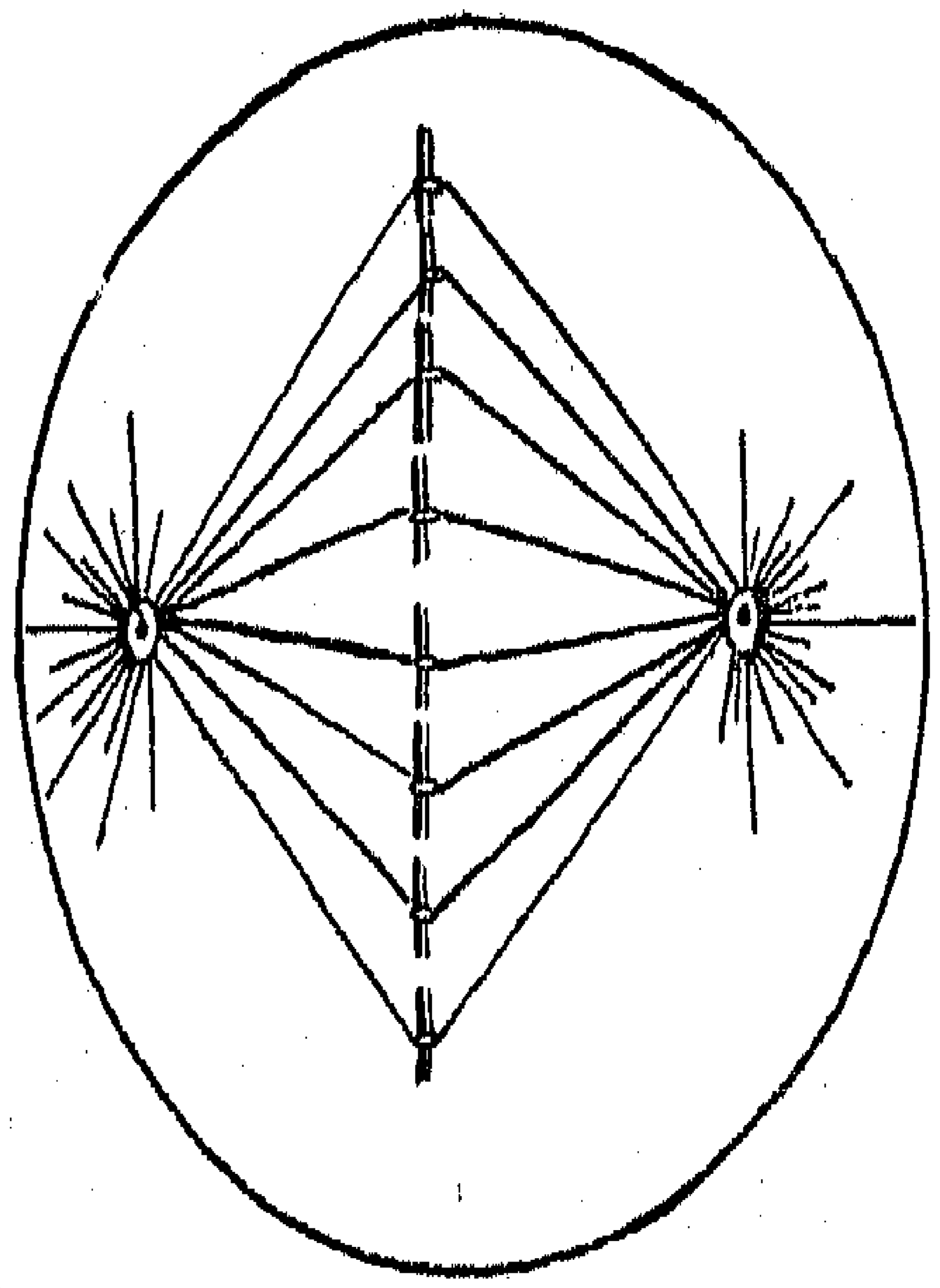
Fig. 13. Spindle occupies central position, fibres elongate, centrosomes occupy opposite poles of nucleus, chromosomes contract.



METAPHASE

Fig. 14. The longitudinally double chromosomes arrange in an equatorial plane—each daughter chromosome being attached to the opposite poles by means of spindle fibres.

3. Anaphase—The separation of the daughter chromosomes and their movement to the opposite poles of the spindle occurs at this stage. This is a stage of short duration, say two to three minutes, but involves great activity. The separation of the daughter chromosomes occurs as if each half was repelled from the other half and was pulled to the poles. Separation occurs first at the **centromere** which is also the point of attachment of the spindle fibre. Probably the contraction of the spindle fibres furnishes the pulling force for the daughter chromosomes to move towards the opposite poles.

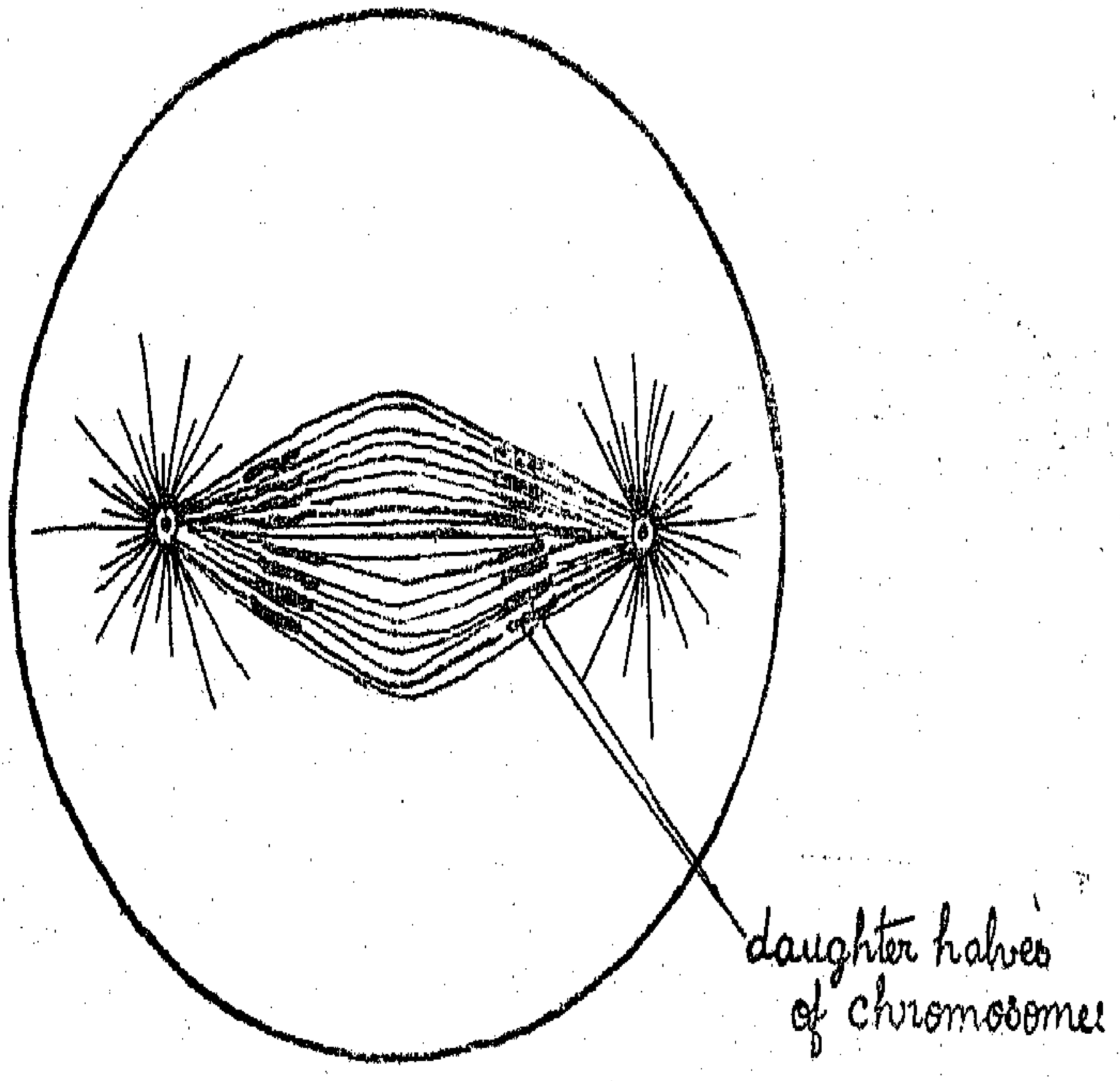


METAPHASE

Fig. 15. Diagrammatically represented.

During the last phase of the anaphase stage, the middle region of the spindle elongates. A furrow makes its appearance around the cell and forms the furrow for division of the cell into two in a plane at right angles to the long axis of the spindle.

4. Telophase—The chromosomes of each pole become closely grouped together by coiling up. They undergo a process of recombination and recondensation. The chromosome-material ultimately assumes the arrangement characteristic of the resting nucleus. The spiral arrangement of the chromatin material and the chromosomes can only be seen at the next dividing stage of the cell. According to the present view the chromosomes persist throughout in some form even between the divisions but that they cannot be made out or observed in the **resting nucleus** (the stage when it is not preparing for or undergoing division).



ANAPHASE

Fig. 16. Division of the chromosomes and movement of the daughter halves towards opposite poles—the middle region of spindle elongates.

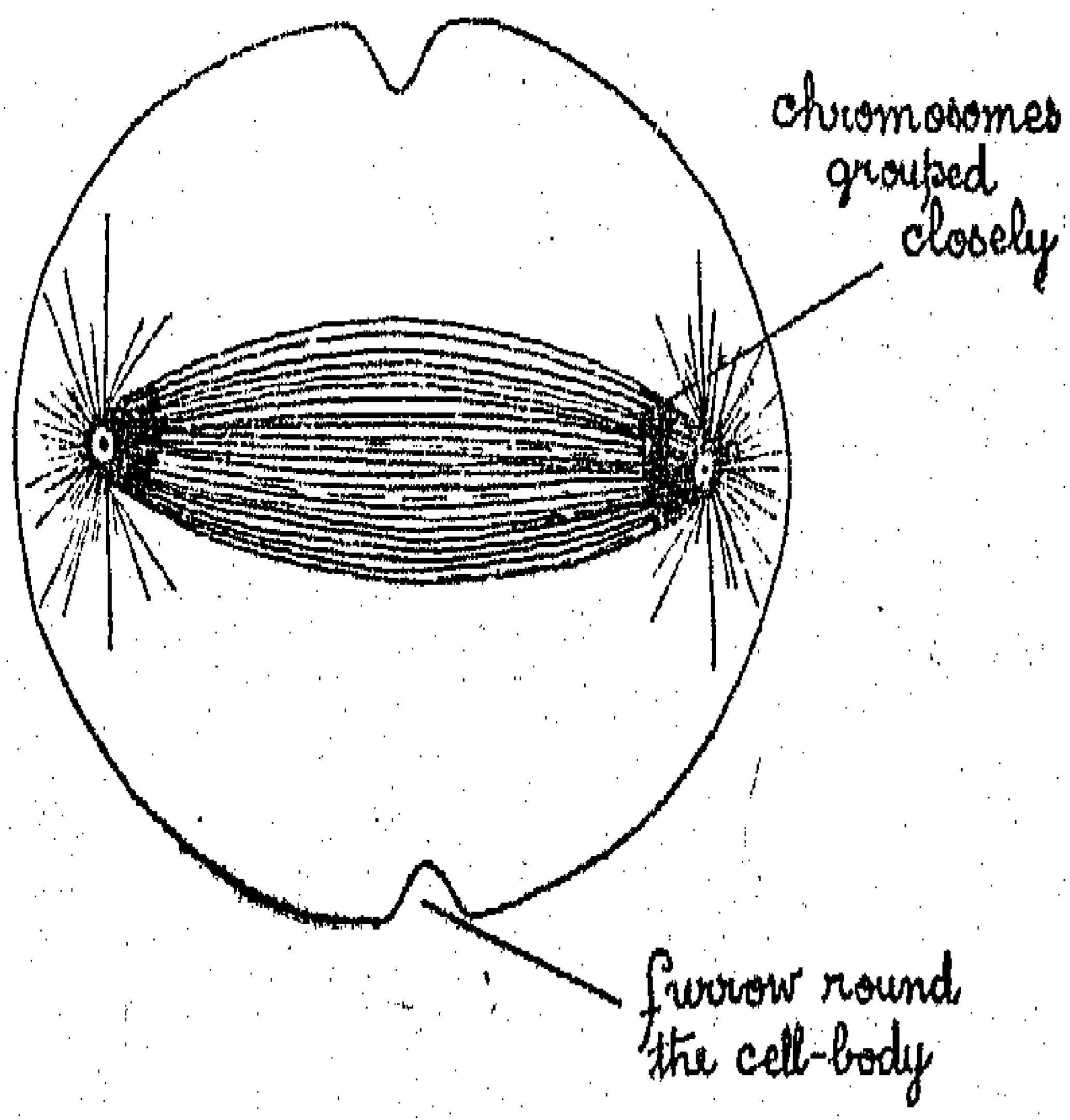
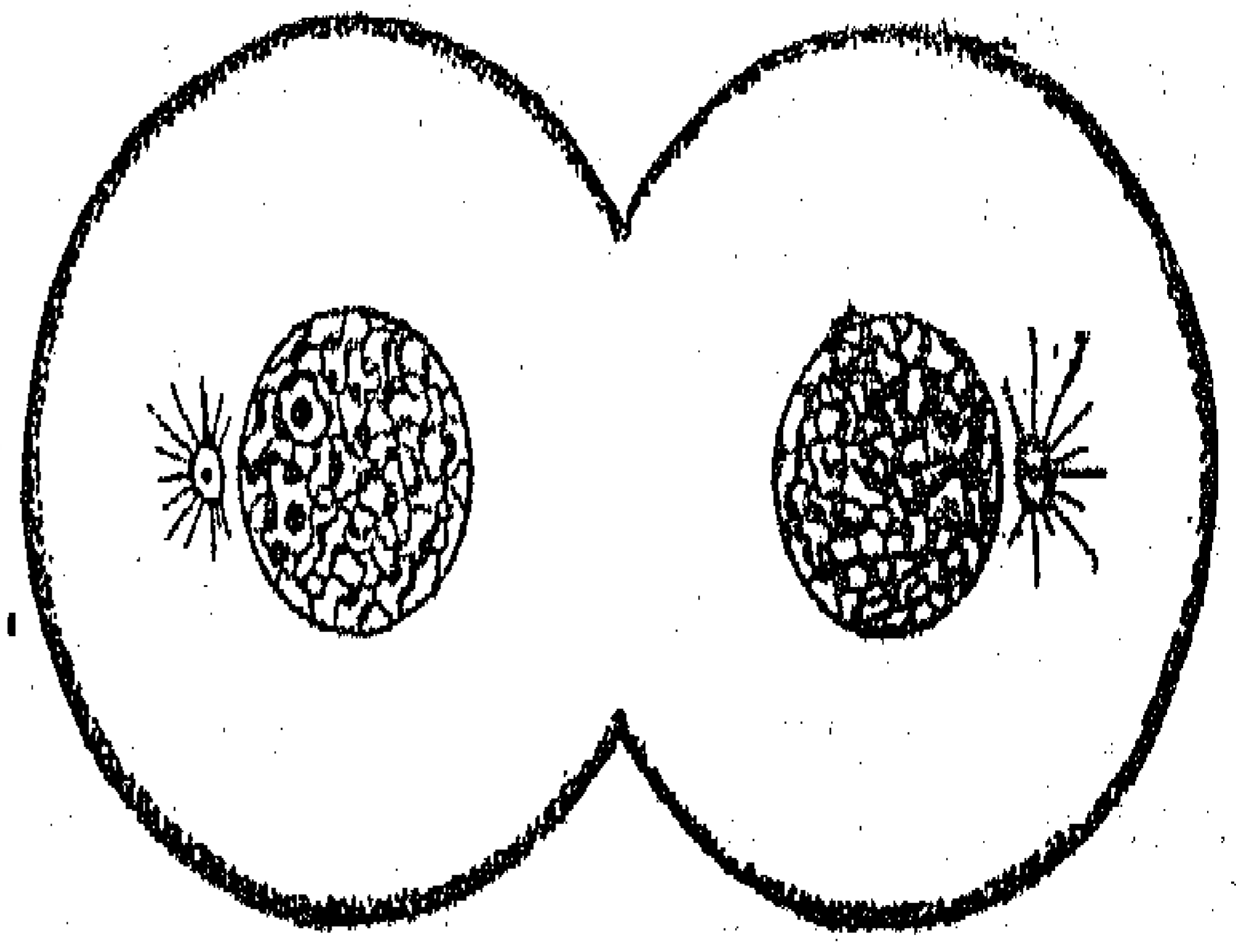


Fig. 17. **TELOPHASE**

The nucleoli reappear and the nuclear membrane is reformed around each group of chromosomes so that two daughter nuclei are formed. The furrow round the equatorial region of the cell body deepens and finally the cell divides into two daughter cells, Now the Mitosis is completed.



TELOPHASE

Fig. 18. The nuclear membrane appears, the chromosome material assumes the original condition of the resting nucleus.

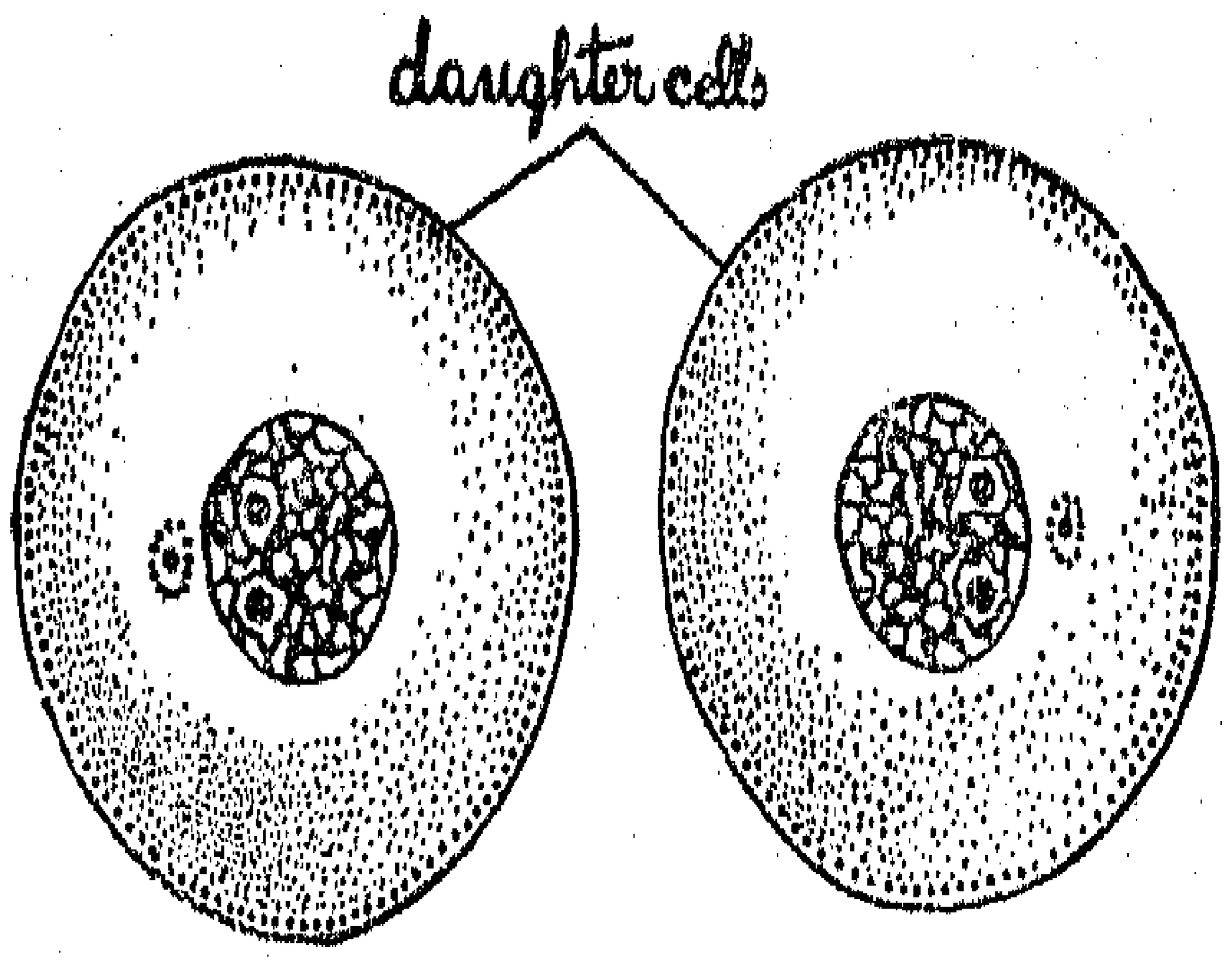


Fig. 19. The two daughter cells formed as a result of mitosis.

It may be added that a constant number of chromosomes is found in all the *body cells* (**somatic cells**) of an animal. The number is characteristic of the species, for example man has forty-eight chromosomes in all his body cells. During the process of mitotic division the chromosomes divide longitudinally and separate into two separate groups, each group constituting a daughter nucleus Each of the daughter nuclei resulting from mitotic type of division receives a set of chromosomes identical with that of the parent nucleus. The characteristic feature of the mitotic type of cell division is that **the number of chromosomes in the daughter nuclei remains the same as that of the parent nucleus.**

In cases where the centrosomes are found within the nucleus itself the nuclear membrane does not disintegrate and the mitotic figure remains confined within the boundaries of the nucleus. In higher plants and many protozoa, no centrosomes are found but their absence does not matter for the process. The asters are not formed in their cases. In case of protozoa, polar plates are formed out of the cytoplasm at the poles and they take the place of centrosomes.

As soon as the nuclear division is complete and the two daughter nuclei are formed the cytoplasm also divides. According to Doncaster division of the cytoplasm (cleavage) occurs due to diminished surface tension around the equator of cell which is far away from poles and consequently a furrow develops and divides the cell. Cleavage always occurs at right angle to the long axis of the spindle. The metochondria and Golgi bodies also divide and are equally distributed to the daughter cells. The division of Mitochondria is known as **chondriokinesis.** According to some the mitochondria do not undergo any division.

2. **Amitosis** (or direct nuclear division)—In this case the nuclear membrane does not break down and the chromatin material too does not undergo changes involving rearrangements in a complicated manner. On the other hand, the nucleus in a simple way divides into two equal parts. In such a division no mitotic figure-spindle, chromosomes etc. are discernible. Such a division is characteristic of the macronucleus of ciliates and also occurs in some other Protozoa. In amitosis the nucleus simply elongates and then a constriction appears which deepens and divides it completely. It differs from mitosis in the fact that the nuclear membrane remains intact and no chromosomes, centrosomes and spindle fibres appear. The entire dividing force rests inside nucleus. However a longitudinal fibrillation inside nucleus may occur.

3. **Meiosis** (Reduction Division)—In this kind of nuclear division, the number of chromosomes in the daughter nuclei is reduced to one half of that of the parent nucleus. The meiotic divisions always precede fertilization in the gametes of the multicellular animals. All animals are characterized by a definite number of chromosomes which is characteristic of the species to which the animal belongs. Zygote is formed as a result of fusion of male and female nuclei each bringing its own set of chromosomes. Thus the zygote contains double the number of chromosomes present in each individual gamete. All the body cells (somatic cells) of an animal contain this diploid number of chromosomes which is fixed for the species. During gametogenesis reduction occurs in the chromosome number with the result that the gametes come to have only half the number of chromosomes compared to the number of chromosomes in the somatic cells. This reduction of chromosome number to one half of that of somatic cells is brought about during one of the two maturation divisions by a typical process of cell division known as **meiosis** or **reduction division,** During fertilization the male and female gametes (the sperm and the ovum) unite and form the zygote restoring thereby the diploid number of chromosomes. The zygote thereafter always divides mitotically during the entire developmental process of the embryo so that the somatic cells invariably contain the diploid number of chromosomes.

The meiosis can be considered under the same four stages as the mitosis namely (i) Prophase, (ii) Metaphase, (iii) Anaphase and (iv) Telophase.

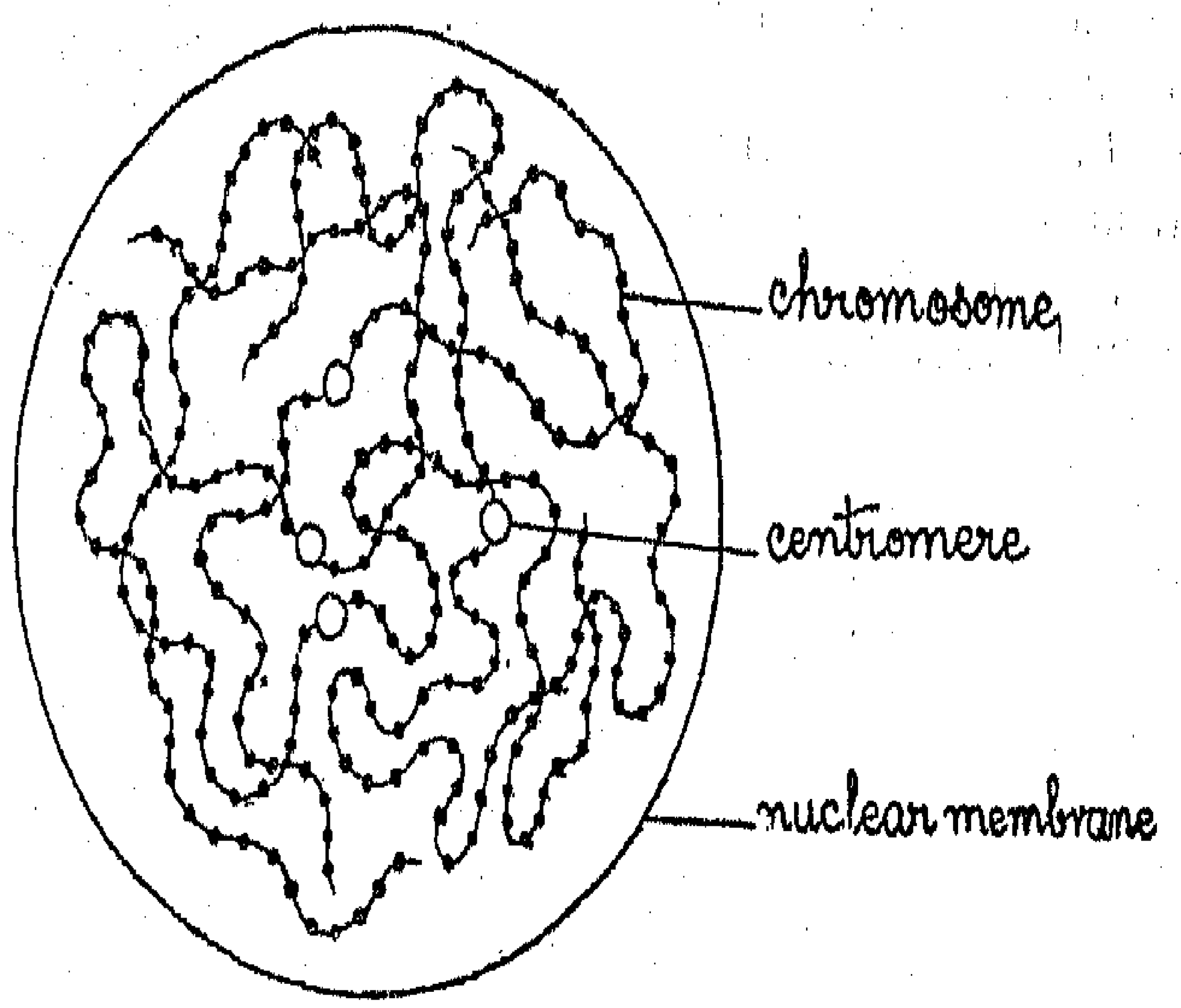


Fig. 20. (i) **LEPTONEMA STAGE**
(From various sources).

(i) The **prophase** of meiosis occurs in five stages namely (i) **leptotene** or **leptonema stage,** (ii) **zygotene** or **zygonema stage,** (iii) **pachytene** or **pachynema stage,** (iv) **diplotene stage** and (v) **diakinesis.** During the (i) **leptotene stage** the long thread like chromosomes arranged at random become distinct.

In the (ii) **zygotene** stage the homologous chromosomes come close and get themselves arranged in pairs without fusing. The chromosomes undergo a process of contraction simultaneously.

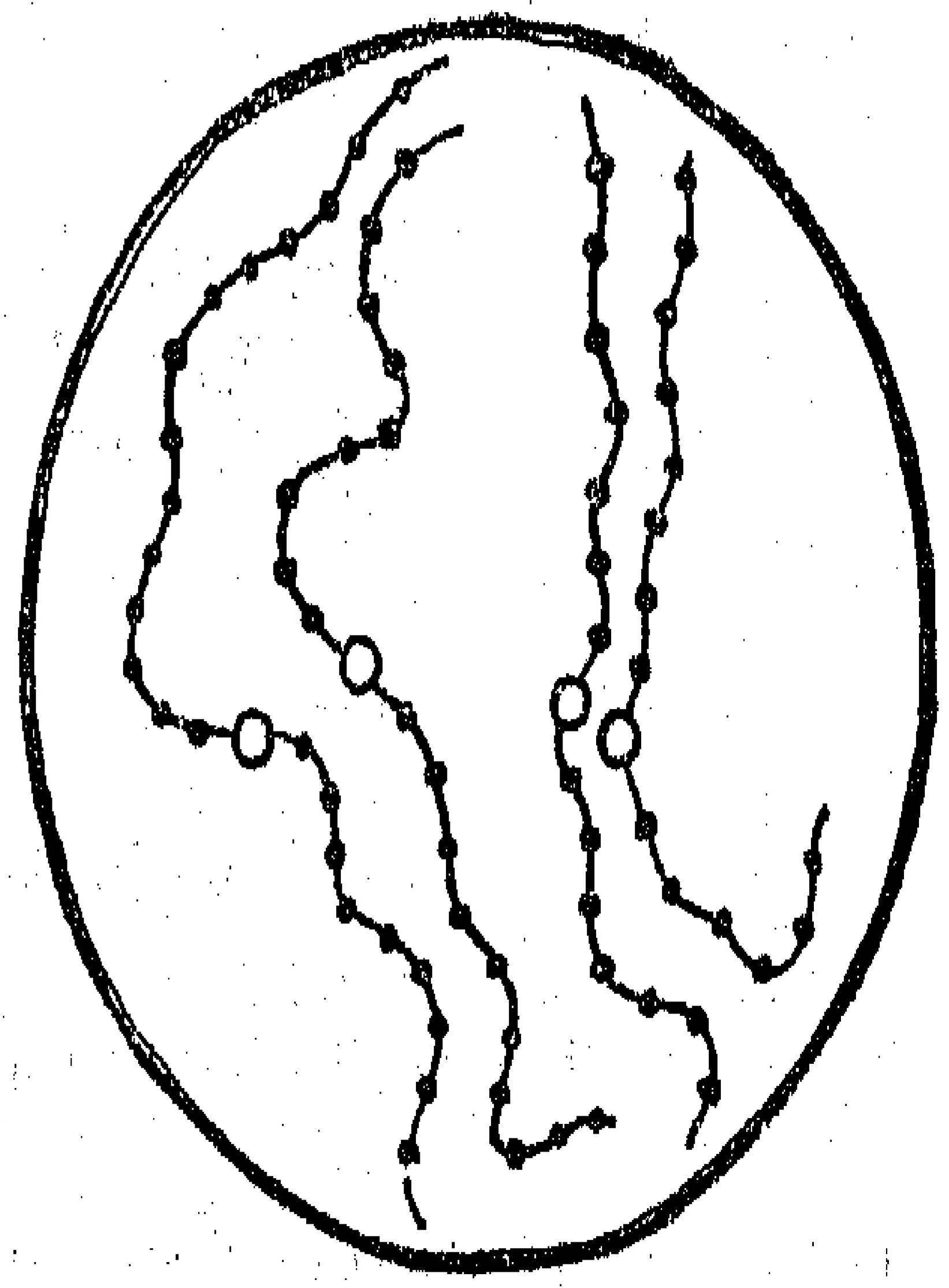


Fig. 21. (ii) **ZYGONEMA STAGE**

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In the (iii) **pachytene stage** the pairing attains completion and each thread is double. If there were four chromosomes to begin with, only two bivalents are visible at the pachytene stage. The chromosomes contract, thicken and shorten still more. During the (iv) **Diplotene stage** each chromosome splits up longitudinally into two chromatids. The chromatids attract each other but the homologous chromosomes start repelling each other. (v) **Diakinesis**—The chromatids contract still further—each one of them arranges in a double spiral. The nuclear membrane disintegrates and the chromosomes occupy a definite position on the spindle.

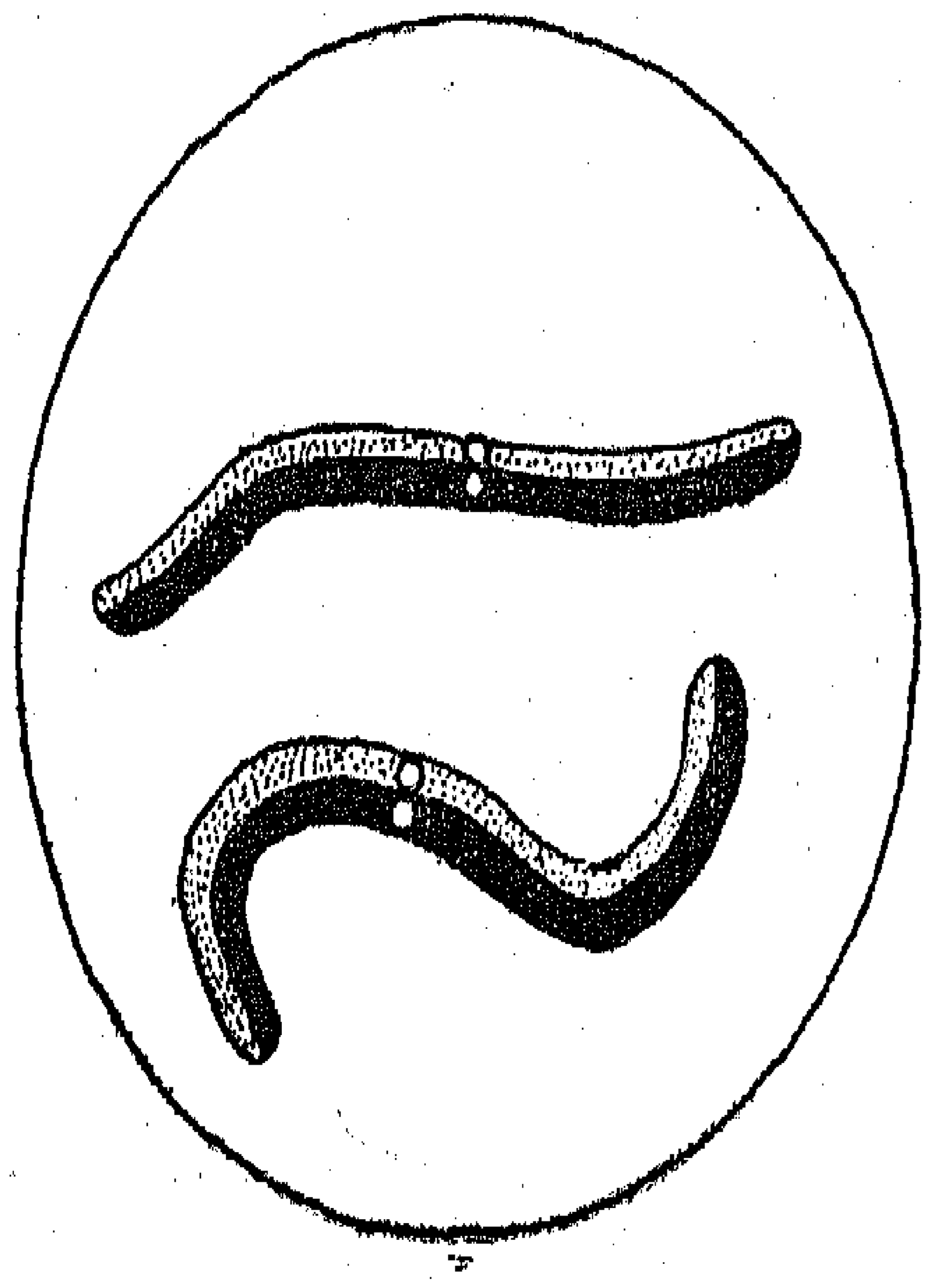
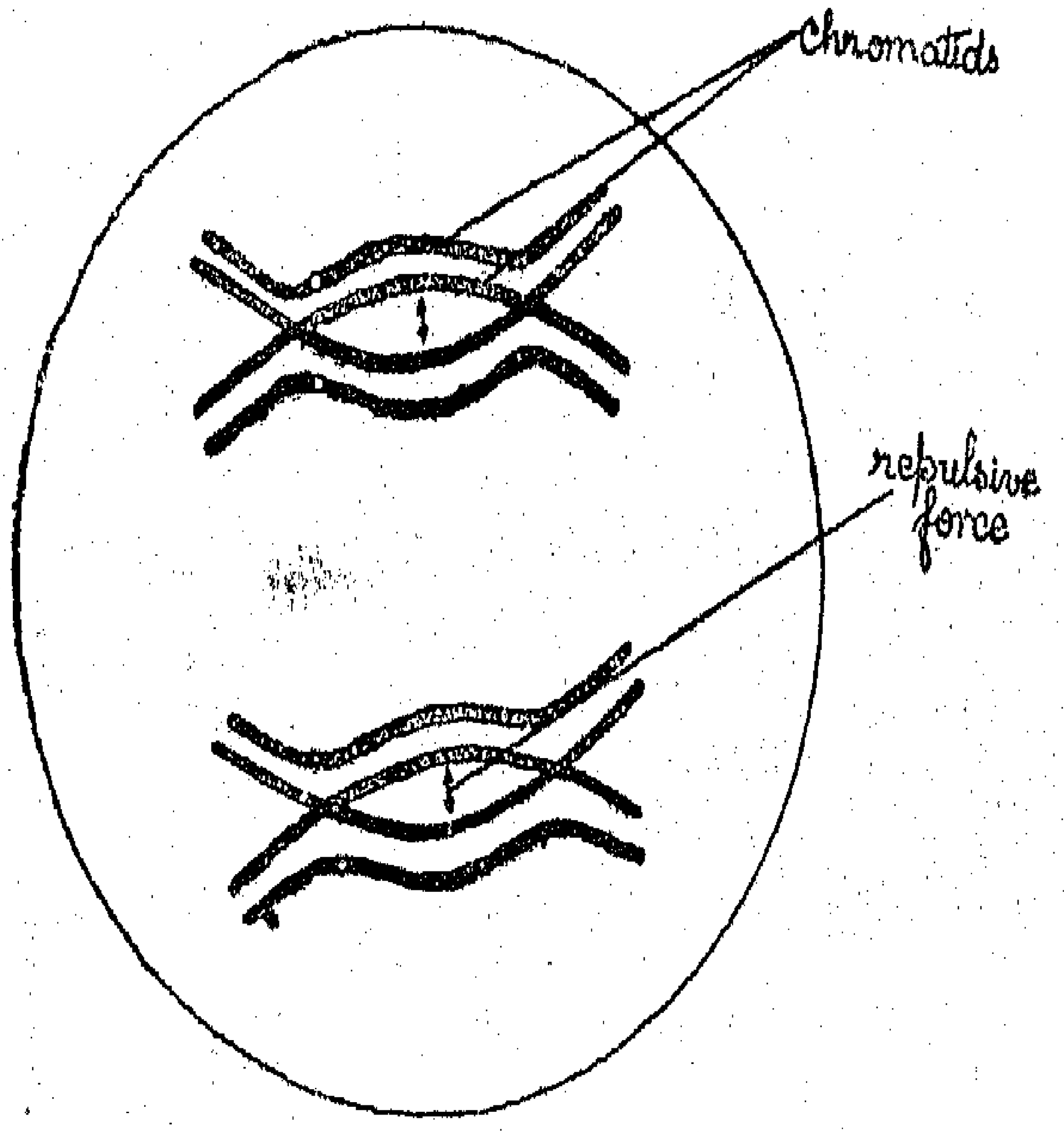
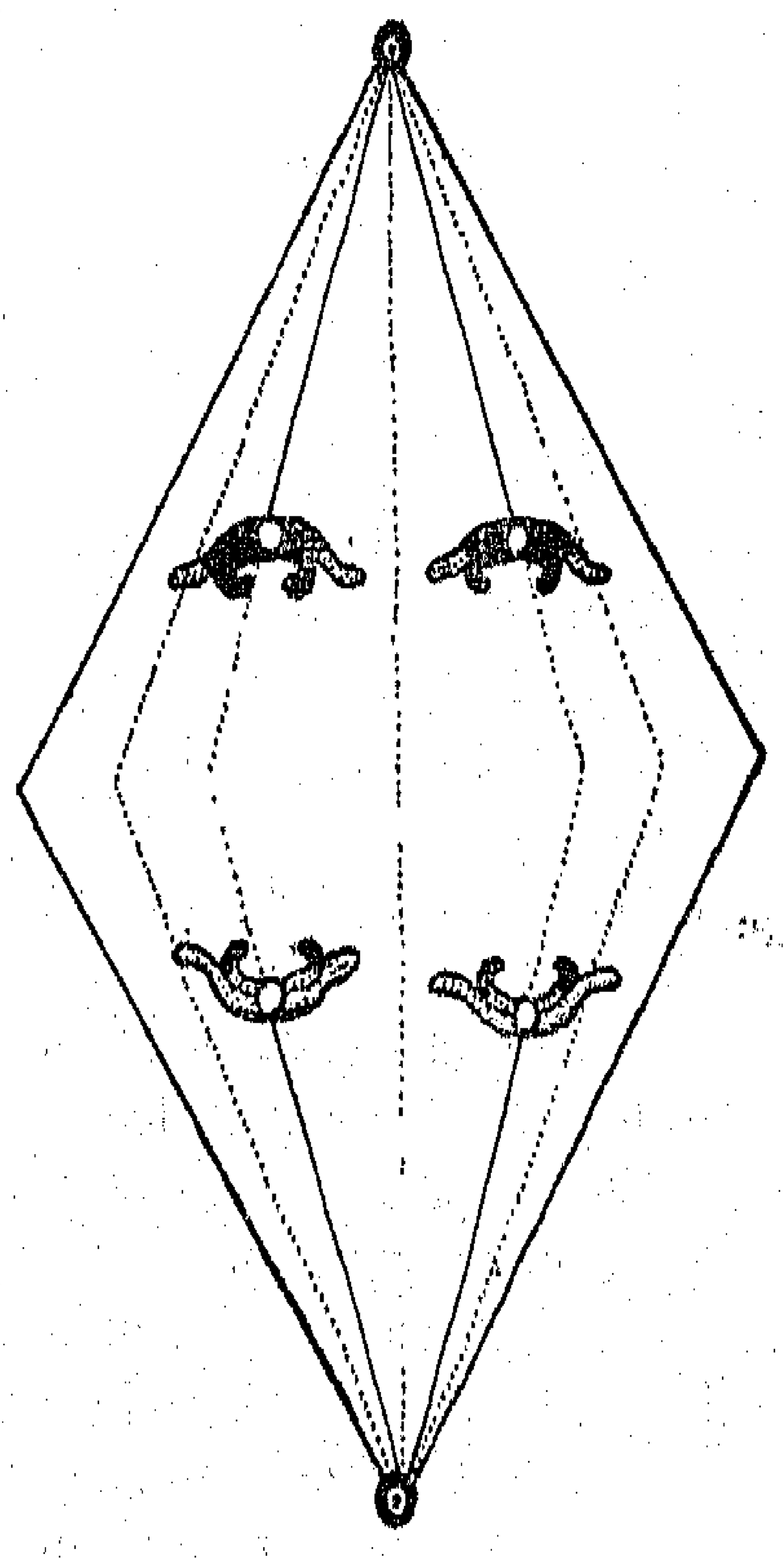


Fig. 22. **PACHYNEMA STAGE**



DIPLOTENE STAGE

Fig. 23. Longitudinal splitting of chromosomes breaks occur in them, maternal and paternal chromosomes interchange parts.



ANAPHASE

Fig. 24. Chromatids of homologous chromosomes move towards opposite poles of spindle which elongates in the middle region.

Metaphase—The chromosomes become arranged on the equatorial plane. The centromeres remain at equal distances from the equator.

3. **Anaphase**—The centromeres and the chromatids of the homologous chromosomes move towards the opposite poles of the spindle. The spindle elongates in the middle region so that the two groups of chromosomes separate completely. It is however remarkable that the chromosomes of the anaphase are not completely similar with those of the zygonema stage. In the pachytene stage, breaks occur in the chromatids and the maternal and paternal chromosomes interchange material. The chromosomes of the anaphase stage represent fresh combinations of the original chromosomes which paired during the zygonema stage.

4. **Telophase**—The chromosomes of each pole become closely grouped together. The chromosome number is rendered haploid or reduced to one half of that of the mother cell. The nuclear membrane is formed round each daughter nuclei; the two daughter cells are ultimately formed.

It will be observed that the meiotic type of division differs radically from the mitotic type of division. *Mitosis is of common occurrence in the cells of the multicellular body while meiosis occurs only during the formation of the germ cells or gametes—the spermatozoa and the ova.* Let us now compare the two processes and put the main dissimilarities in a tabulated form :

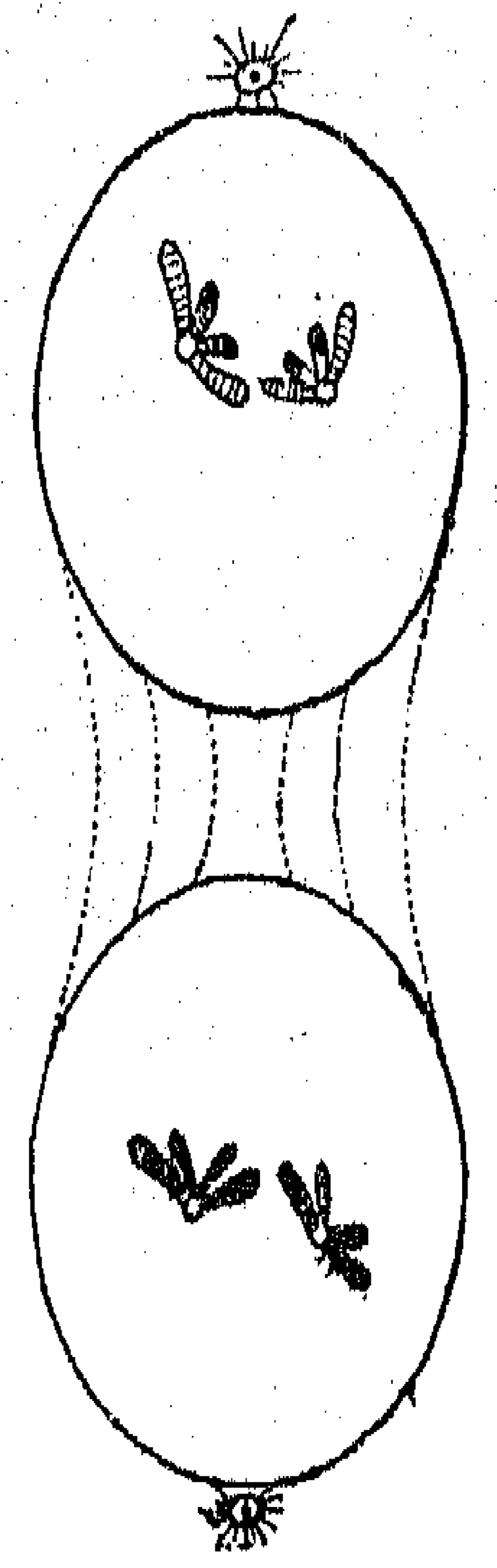


Fig. 25. **TELOPHASE**

S. No.	Mitosis	S. No.	Meiosis (Reduction division)
1.	Occurs in the somatic or body cells of the mutlicellular animals and some protozoa.	1.	Occurs only during the gametogenesis in the spermatocyte or oocyte. One of the two maturation divisions being of the meiotic type.
2.	The number of chromosomes in the daughter nuclei is the same as that of the parent nucleus.	2.	The number of chromosomes in the daughter nuclei is only **one half** of that of the parent nucleus.
3.	The prophase is not of such a long duration. The chromosomes are longitudinally double at the late prophase stage.	3.	The prophase is of considerable duration and shows a series of complicated stages. The long thread like chromosomes are more distinct than in mitosis prophase.
4.	No pairing of homologous chromosomes occurs at the prophase stage.	4.	The homologous chromosomes come close and pair without getting fused.
5.	No interchange of chromosome material or crossing over occurs at any stage during mitosis.	5.	Some chromatids break at the end of the pachytene stage and then join diagonally—the maternal and paternal chromosomes exchange material which in genetical language is commonly termed as **crossing over**. The places where the chromosomes tend to separate are known as **chiasmata**. One or more chiasmata are formed during the diplotene stage.

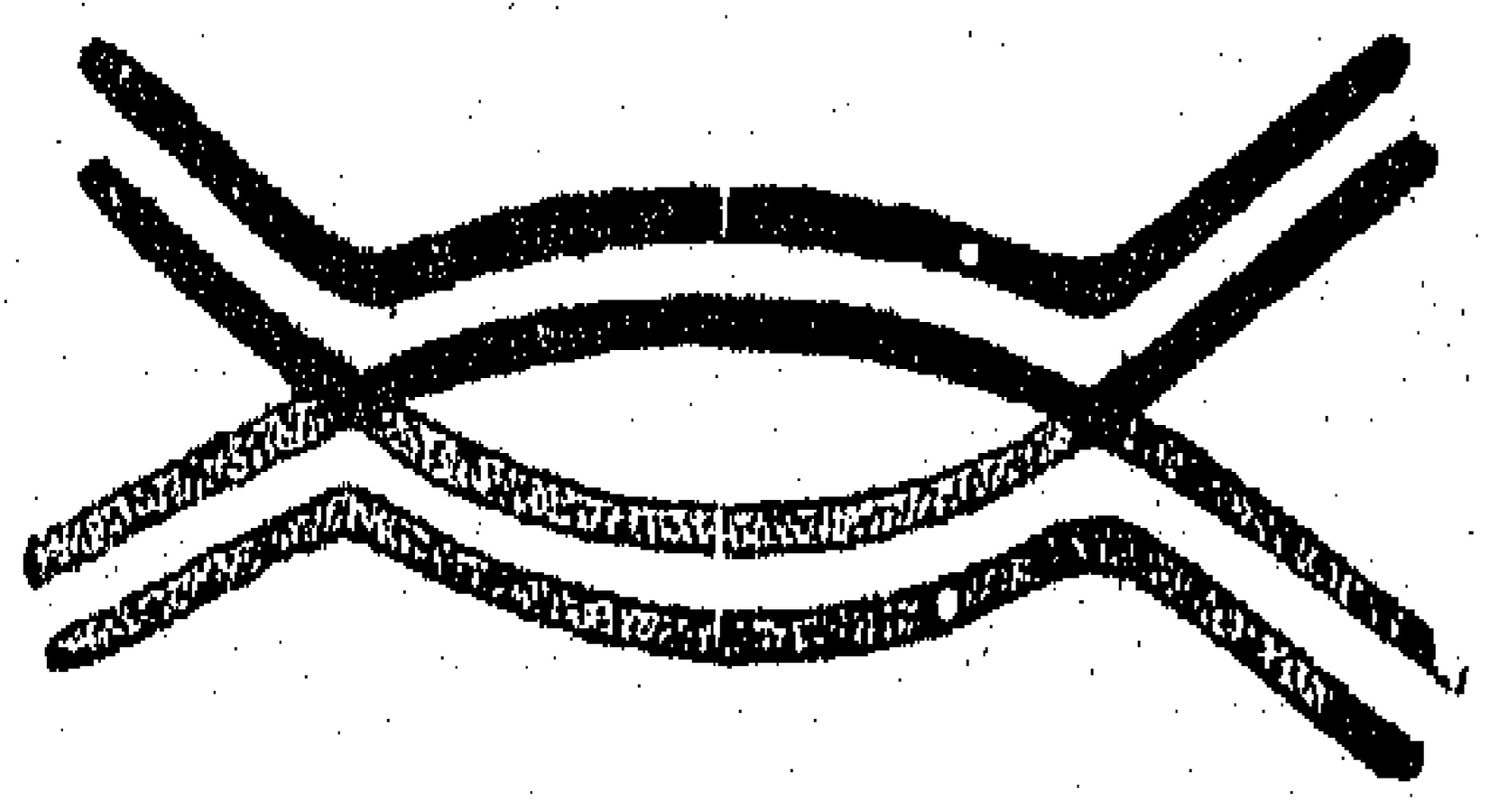


Fig. 26. Parts of homologous chromosomes.

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4

Classification of the Phylum Protozoa

Classify Protozoa giving chief characters and examples of each group. **(L. U., 1956)**

The **Protozoa** are *noncellular* (often described as unicellular) organisms without differentiation into tissues composed of cells. When there are many nuclei in a single protozoon, the regions of cytoplasm under the physiological control of the various nuclei are not fixed; they have intracellular organelles. Reproduction is both sexual and asexual. A sexual reproduction occurs by binary fission, budding or multiple fission. The Protozoa are minute and microscopic organisms with various shapes. All protozoa need ample moisture for their survival; they may be *free-living* in fresh water, soil, salt water, in moist places or may be parasitic on plants or animals. They are solitary or colonial.

The chief criterion for the classification of Protozoa is the presence or absence and the nature of locomotor organellae. The phylum Protozoa is divided into two subphyla and five classes as shown in the following chart.

Phylum **Protozoa**

Subphylum 1. **Plasmodroma** | Subphylum 2. **Ciliophora**

Class 1. **Mastigophora** (Flagellata)	2. **Sarcodina** (Rhizopoda)	3. **Sporozoa**	4. **Ciliata** (Infusoria)	5. **Suctoria**
Ex. *Volvox*, *Euglena*, *Noctiluca*, *Ceratium*, *Trypanosoma*, *Leishmania* *etc.*	*Amoeba*, *Entamoeba*, *Difflugia*, *Arcella*, *Polystomella*, *Globigerina*, *Actinophrys*, *Actinosphaerium*, *Thalassicola*	*Monocystis* *Gregarina*, *Plasmodium*, *Nosema*	*Opalina*, *Paramecium*, *Balantidium*, *Nyctotherus*, *Vorticella*	*Ephelota* *Dendrosoma*

Subphylum I **Plasmodroma**—*The locomotor organellae are flagella, or pseudopodia; all nuclei alike, no nuclear dimorphism, sexual reproduction present: gametes fuse completely.*

Class 1. **Mastigophora** *always bear in their predominant adult stage one or more flagella for locomotion and food capture.* The body-shape is more or less fixed and a definite anterior end is differentiated. Plastids usually accompanied by protien bodies 'pyrenoids' are of frequent occurrence. The Chromoplasts have chlorophyll in many cases which renders the forms green. The nucleus usually has a single central *nucleolus* or *endosome.*

The class is divided into two subclasses: 1. **Phytomastigina** which includes free-living plant like forms with chromatophores, xanthophyll, chlorophyll etc. and 2. **Zoomastigina.**

The subclass 1. **Phytomastigina** is divided into six orders which are given below :

Name of the Order	Examples
1. **Chrysomonadina**....	*Uroglena, Synura.*
2. **Cryptomonadina**...............	*Chilomonas,*
3. **Phytomonadina**.................	*Chlamydomonas, Volvox.*
4. **Euglenoidina**...................	*Euglena.*
5. **Chloromonadina**...............	*Thaumatomastix.*
6. **Dinoflagellata**....................	Noctiluca, Ceratium.

We will briefly deal with the 3rd., 4th. and 6th. of the above orders.

Order **Phytomonadina,** usually fresh water forms, have two flagella and a rigid cellulose membrane over the body, *holophytic* nutrition, a large cup shaped *green chromatophore* and a red stigma or eye spot present. Two contractile vacuoles and a nucleus. Longitudinal binary fission common. Sexual reproduction also occurs. *Volvox,* a colonial form shows clear differentiation between somatic cells and sexual cells ; the colony is hollow and spherical and a physiological continuity exists between the various cells of the body which are connected by means of protoplasmic strands.

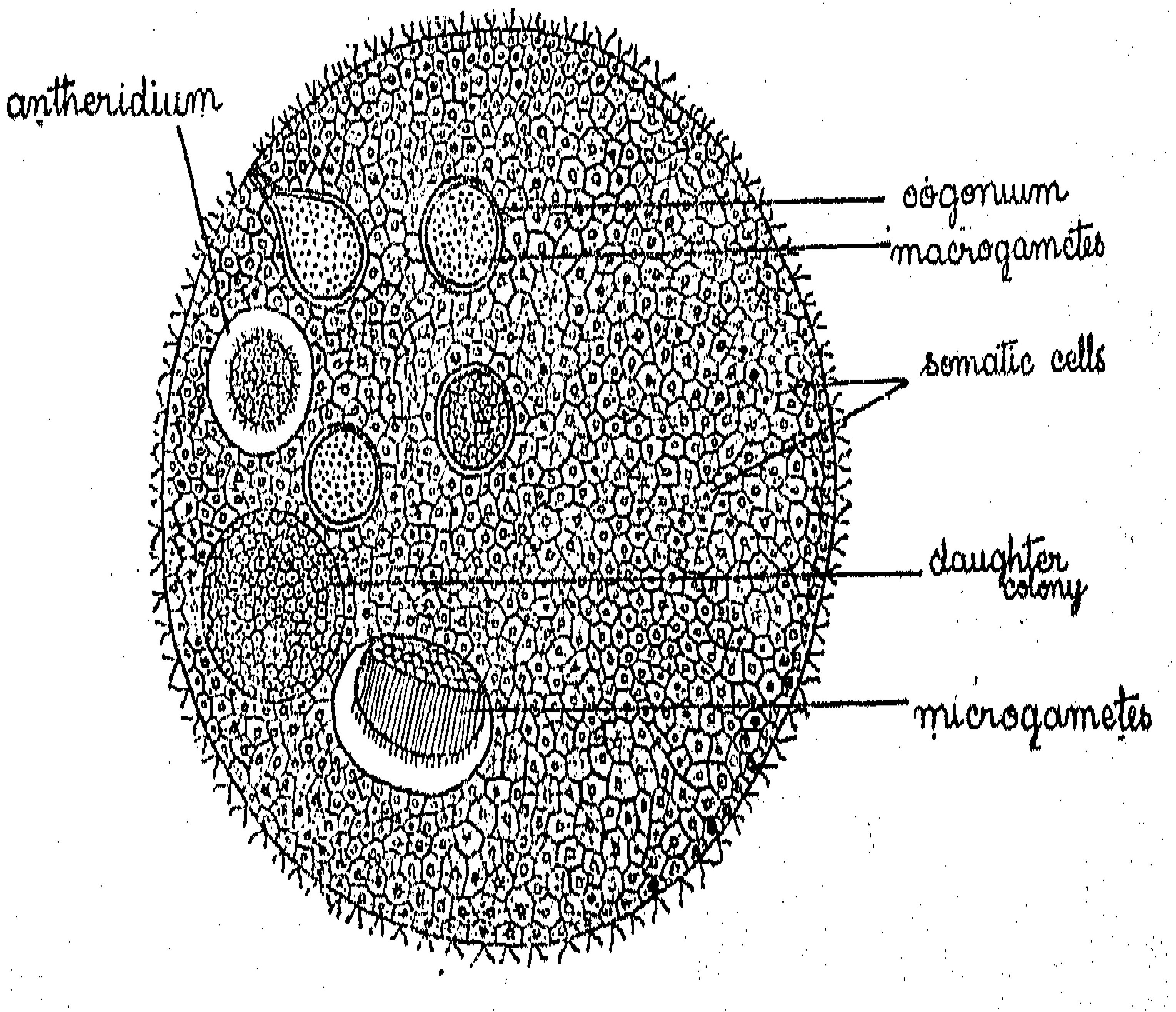

Fig. 27. A sexually mature Volvox colony.

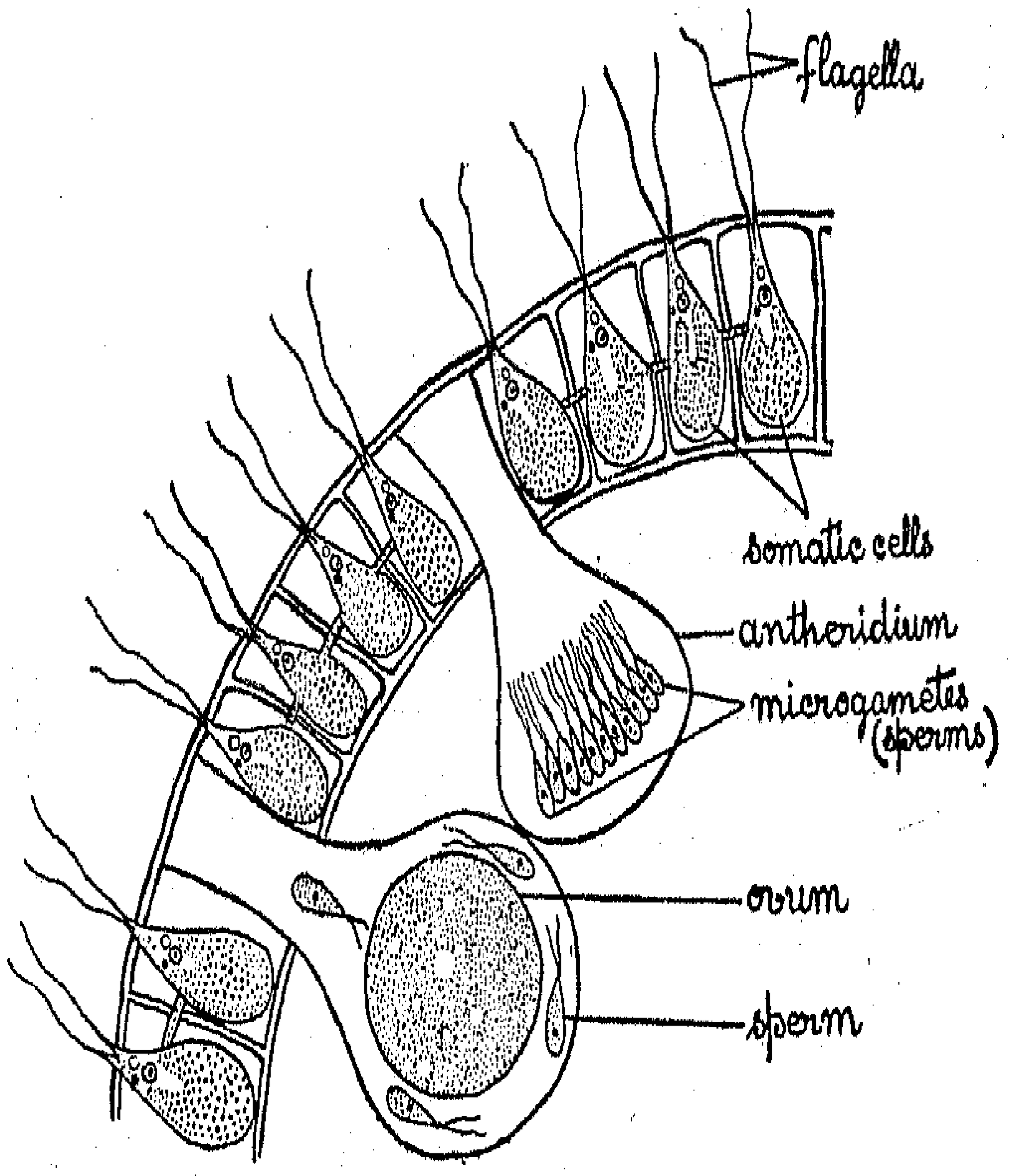

Fig. 28. Development of sex cells in volvox.

Order **Euglenoidina** have a spindle shaped body, a definite form due to thick rigid sometimes striated pellicle ; one or two flagella, a conspicuous red stigma (in green forms) at the anterior end. The anterior end bears the cytopharynx. Nutrition is mostly holephytic. A single large nucleus with an endosome. One or two complex contractile vacuoles. Asexual reproduction by longitudinal binary fission common. Encystment common. True photosynthesis occurs in **Euglena**, a solitary free living fresh water form. Holozoic nutrition is completely absent. It shows euglenoid movements. Euglena has dual mode of nutrition : *holophytic* or *autotrophic* mode predominates in sunlight and saprophytic mode otherwise. This dual mode is called *mixotrophic mode* of nutrition. Euglena's mode of nutrition is summarised below :

1. Holophytic.......(Photosynthesis occurs)
2. Saprophytic.......(Soluble organic matter absorbed through general body surface).

} Mixotrophic

Order **Dinoflagellata**, *generally* marine ; have two flagella ; body covered with a stiff cellulose envelope forming the shell or lorica with grooves for the flagella. The shell has a longitudinal groove known as **sulcus** and a circular ring like groove encircling the body known as **annulus**. The two flagella emerge from pores in the lorica ; one flagellum springs from the sulcus and trails behind and the other arises from the annulus and encircles the body like a girdle. Two noncontractile vacuoles known as **pusules** are found. Nutrition is usually holophytic ; holozoic in forms without chloroplasts. Examples : *Noctiluca* and *Ceratium*.

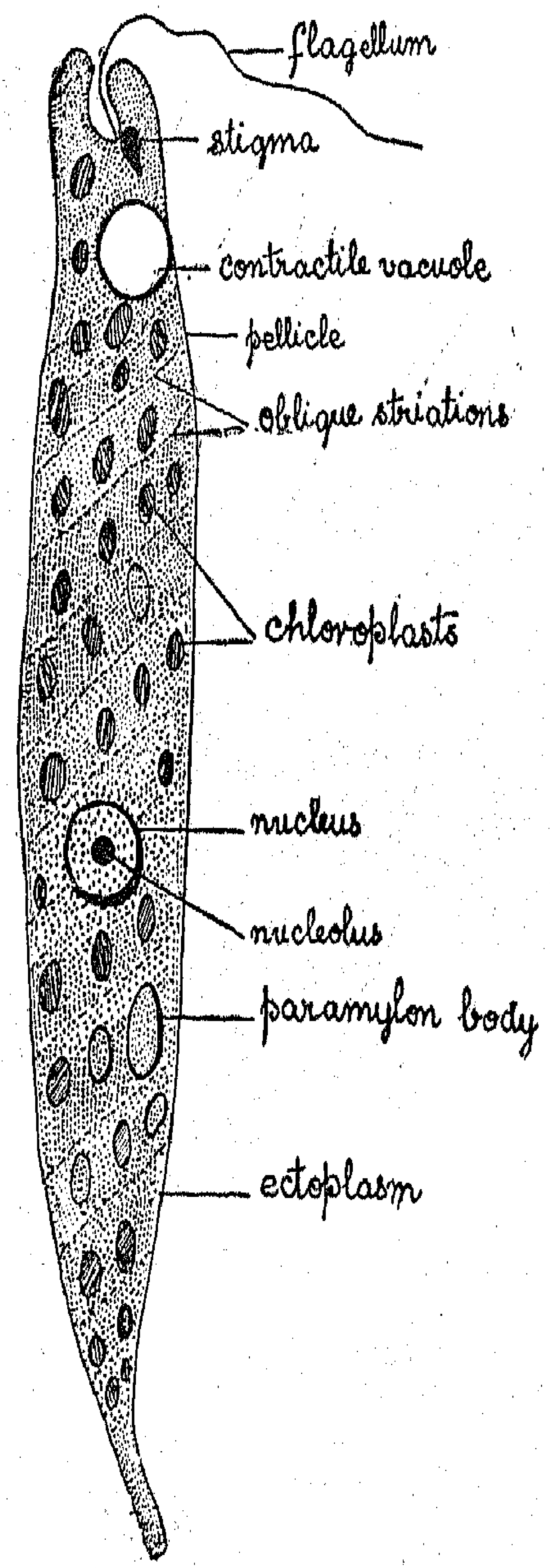

Fig. 29. Euglena.

Noctiluca, marine, lacks chromatophores, hence colourless. Nutrition is holozoic. It is phosphorescent and emits light during night. Sulcus : a median longitudinal groove is present from which a rudimentary longitudinal flagellum arises. The sulcus expands to form a cytopharynx which leads to the mouth. From the mouth a backwardly directed long striated *tentacle* springs ; this is locomotory in function. Annulus or circular groove is vestigial.

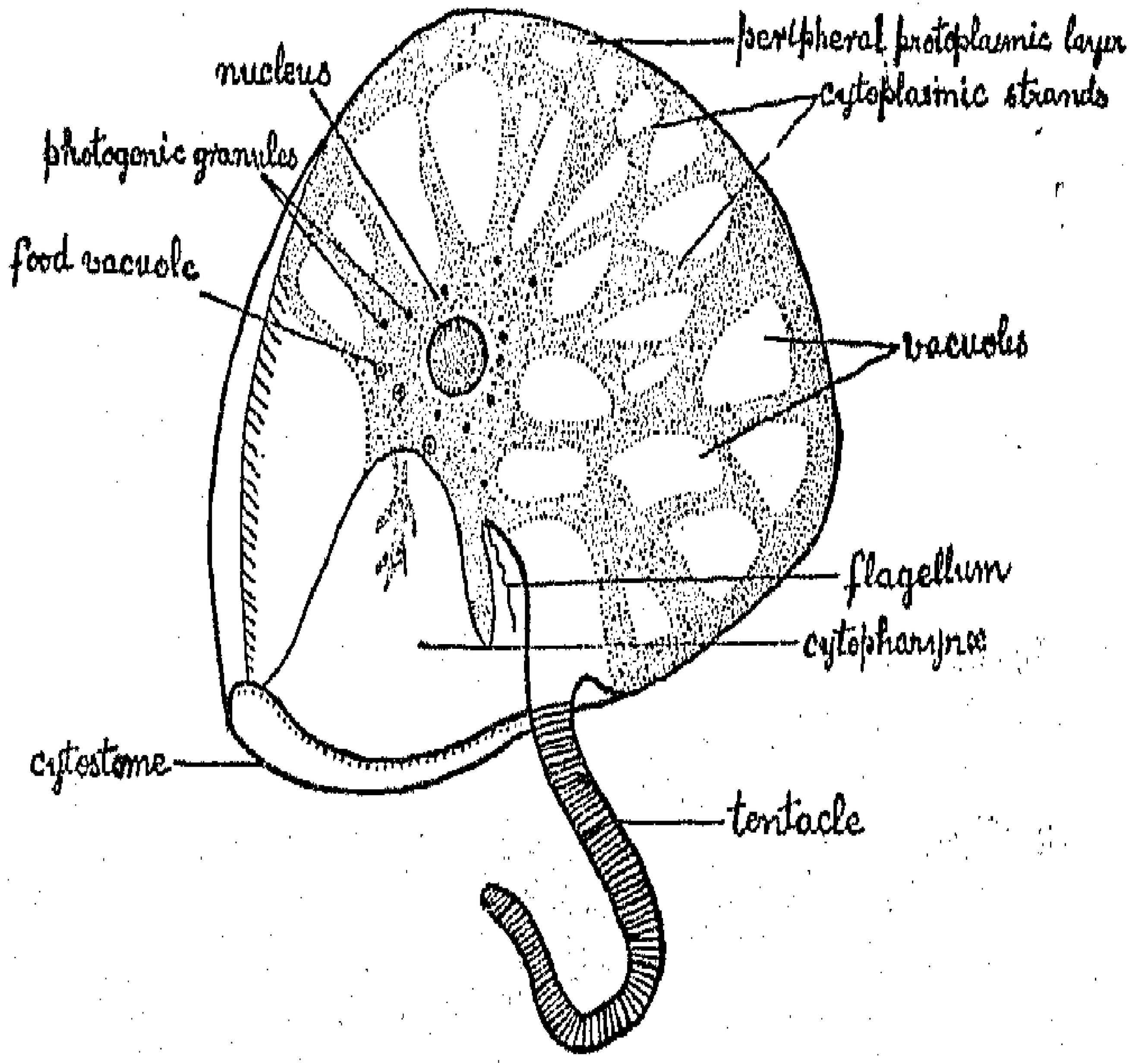

Fig. 30. Noctiluca.

Ceratium has both marine and fresh water species ; body covered over by a stiff cellulose envelope covered over by hard plates ; the complex shell has characteristic grooves. The covering hard plates are variously sculptured and have perforations. There are two grooves on the shell : a longitudinal groove, the *sulcus* on the ventral surface and a transverse equatorial groove, the annulus which surrounds the body like a girdle. From the sulcus arises a forwardly directed flagellum which mainly serves for propulsion. The second flagellum lies in the **annulus**. There are three long spines or horns : *an apical spine* and two *antapical spines* ; the number of the latter varies from 2 to 4.

Subclass 2. **Zoomastigina** are forms without chlorophyll ; their animal nature is more distinct ; they have often more than two flagella and in addition *pseudopodia* ; a single nucleus ; they are mostly parasitic in man and other animals. This subclass is divided into the following four orders of which *Protomonadina alone will be briefly dealt here.*

Order 1. **Protomonadina**....... *Trypanosoma, Leishmania*
„ 2. **Polymastigina**.......... *Trichomonas, Giardia.*
„ 3. **Hypermastigina** .... *Trichonympha.*
„ 4. **Rhizomastigina**......... *Mastigamoeba.*

Order **Protomonadina** include small sized colourless solitary or colonial flagellates ; many live in man. The body is slightly amoeboid and is covered over by a very thin coat of **cuticle**. The forms have one or two flagella which may be even up to six ; when only two, they are unequal. In parasitic forms when an undulating membrane is present, the flagellum forms its outer border. In parasitic forms nutrition is saprozoic.[1] Asexual reproduction occurs by longitudinal binary fission. This order is of considerable biological and economic importance as the disease producing trypanosomes are included in it. Dimorphism or polymorphism occurs in the life-cycle of Trypanosomes. This order also includes choanoflagellates (Proterospongia) which have a large collar from the centre of which arises a long flagellum. Ex. *Proterospongia.*

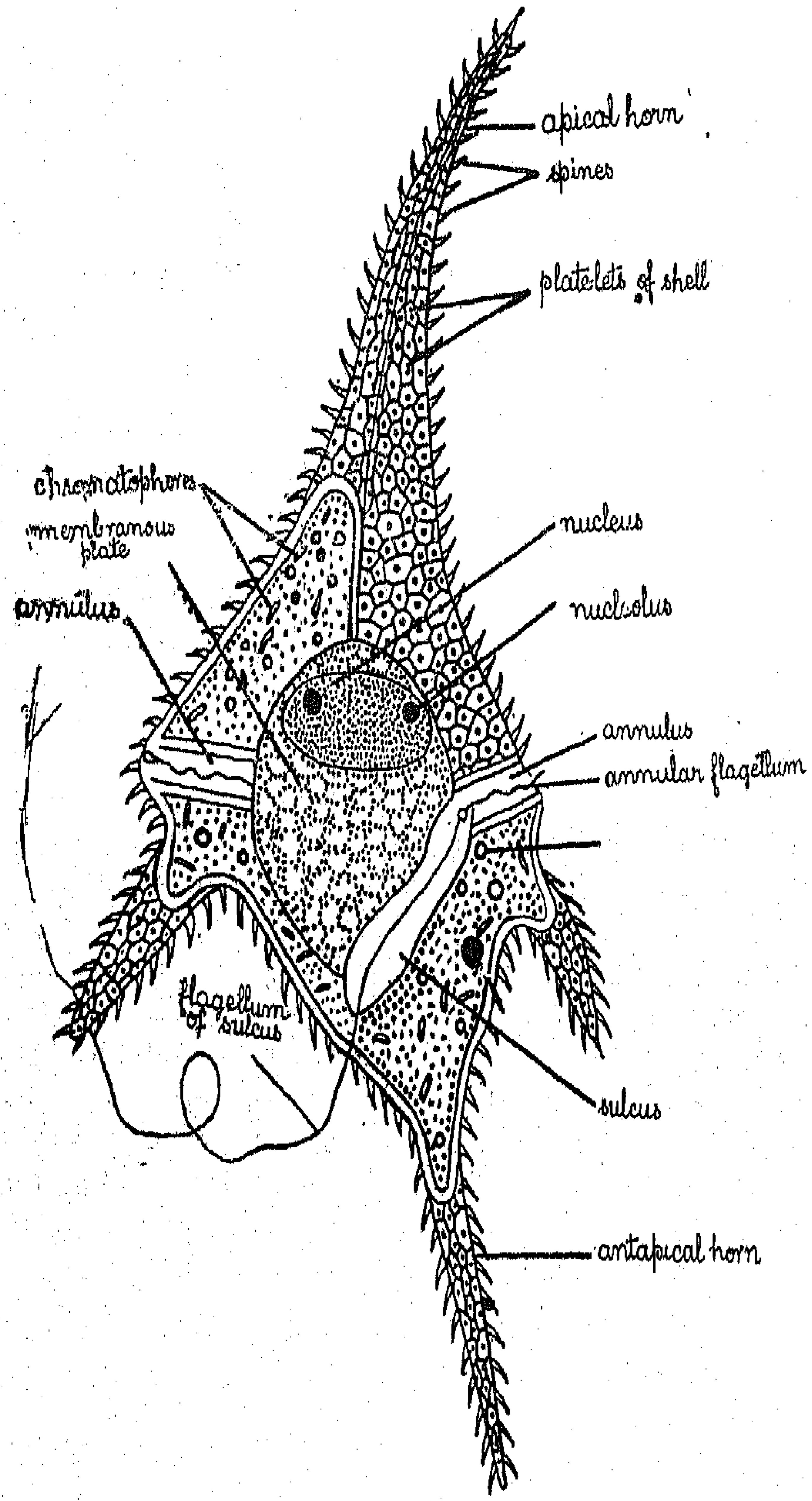

Fig. 31. Ceratium hirudinella (After various authors).

The most important are the *trypanosomes* found in the blood of vertebrates; in man they cause serious diseases. *Trypanosoma gambiense* causes **Gambian sleeping sickness** in man, the secondary host being the Tsetse fly *Glossina palpalis. Leishmania donovani* causes in man a fever known as **Kala-azar** or visceral Leishmaniasis.

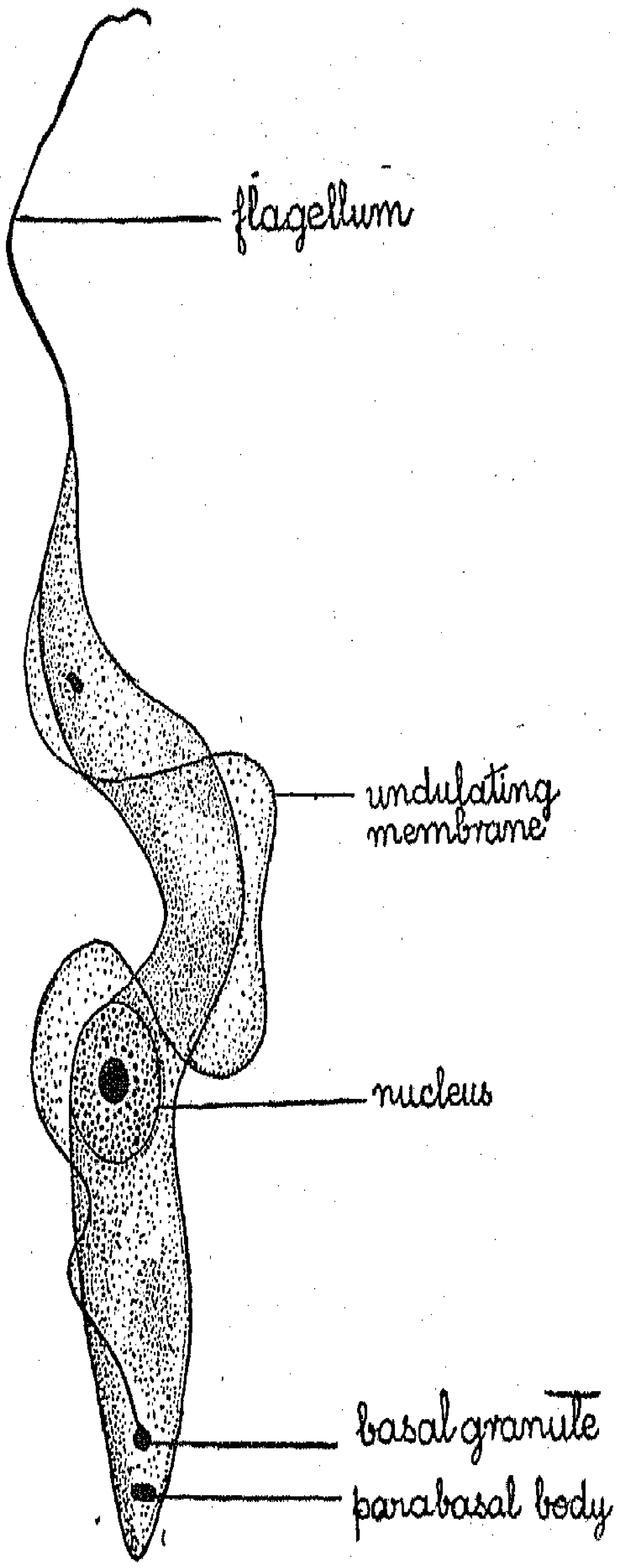

Fig. 32. Trypanosoma (After various authors).

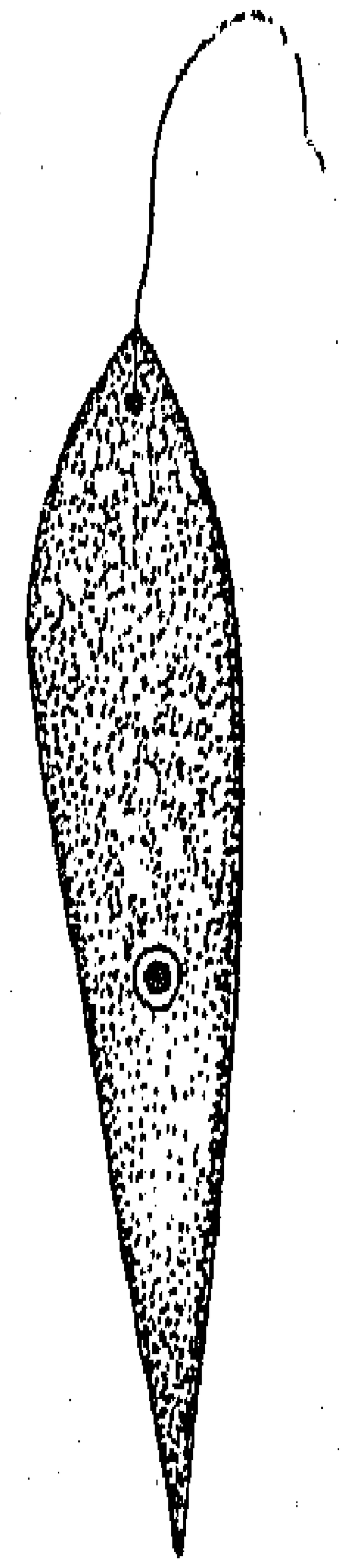

Fig. 33. Leishmania donovani producing kala-azar.

Class 2. **Sarcodina** (Rhizopoda): *The amoeboid phase is predominant; temporary outpushings of the protoplasm or the pseudopodia are formed anywhere on the body surface. The pseudopodia are the food ingesting and locomotory organellae. The body shape changes constantly. Contractile vacuoles are found but they lack feeding canals. Holozoic mode of nutrition is common and so is the asexual reproduction by binary fission.* Encystation is common. Some stages of the life-cycle may be flagellated. A shape giving pellicle is generally not found. A protective, internal or external shell made up of chitin, silica, lime, foreign particles, sand particles, sponge spicules etc., glued together by sticky secretions may be present. The shell when present has one or more pores through which pseudopodia project out. The cytoplasm may be differentiated into ecto—and endoplasm. The pseudopodia may be (i) *lobopodia*, (ii) *filopodia* (iii) *rhizopodia* or (iv) *axopodia*.[1]

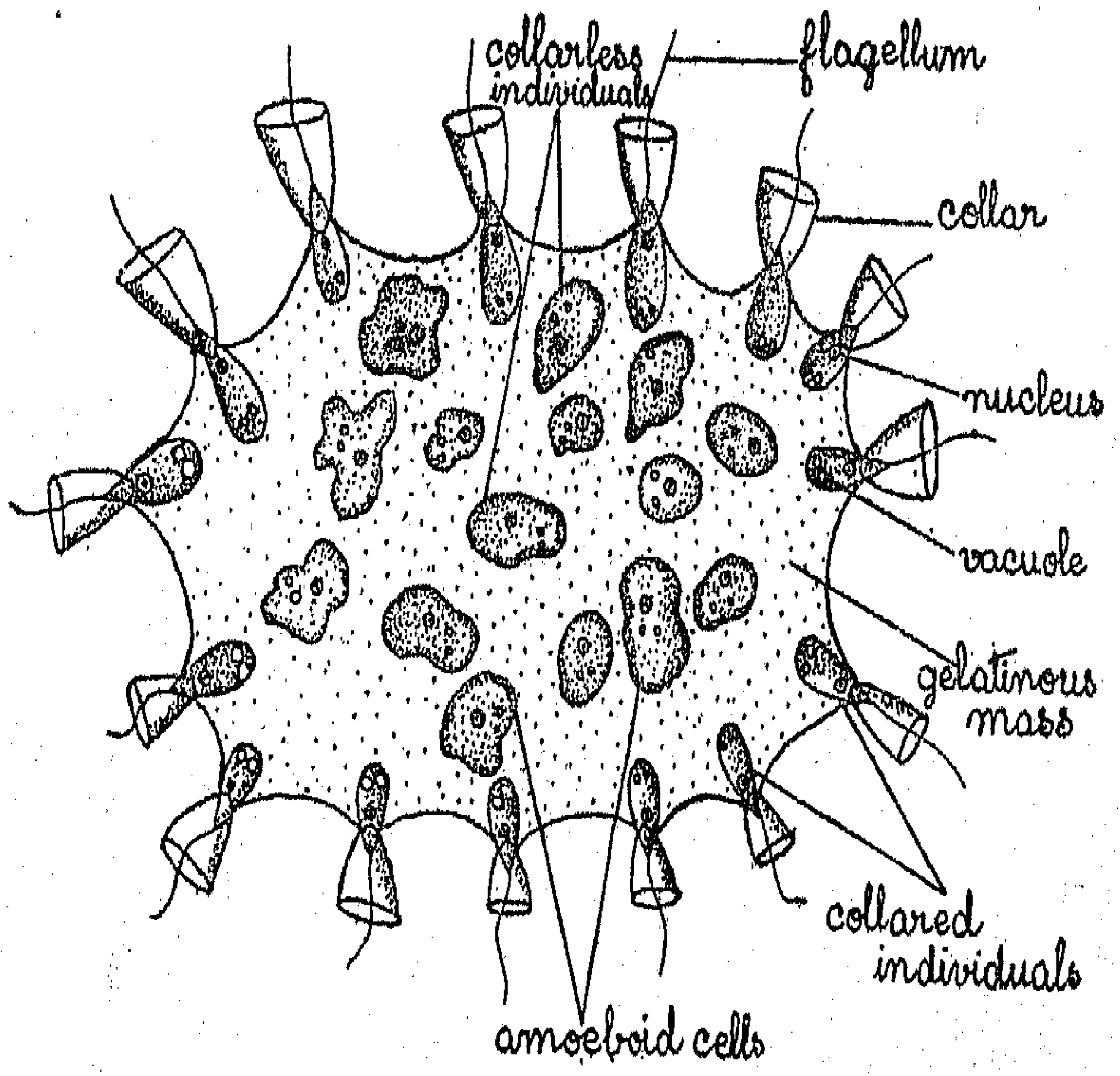

Fig. 34. Proterospongia (After various authors).

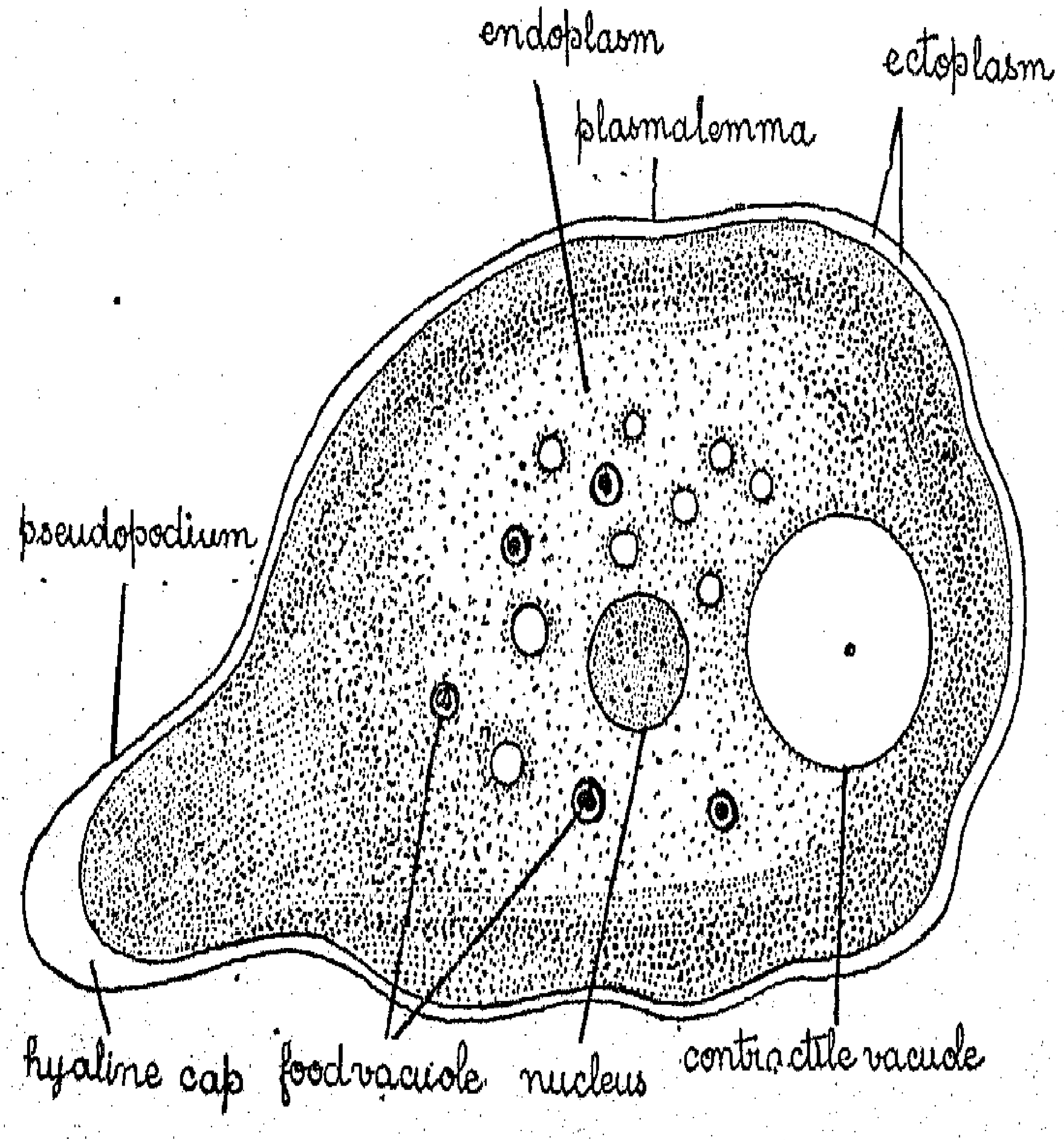

Fig. 35. Amoeba limax.

The class **Sarcodina** is divided into the following five orders depending upon the character of pseudopodia, number of nuclei, presence or absence of an internal or external shell.

Order 1. **Lobosa** (or Amoebina) possess lobose pseudopodia (short and blunt pseudopods) ; cytoplasm is differentiated into a hyaline *ectoplasm* and a vacuolated *endoplasm* typically with a single vesicular nucleus. Some forms are binucleate or multinucleate. Multiplication occurs by binary fission or sometimes multiple fission may occur. Encystment may occur prior to the divisions. Syngamy may also occur (**Syngamy**=fusion of gametes,—coalescence of the two nuclei as well as the cytoplasm,—the resulting body is known as **Zygote**). In some cases union occurs between adults after which active multiplication occurs. This is known as *hologamy*. Lobosa are found in fresh water, sea-water or soil. Some are parasitic on higher animals. There are two suborders : (i) **Gymnamoeba** which have a naked body or may be enclosed in a thin membrane. The body is not covered by a strong shell. Examples are *Amoeba, Pelomyxa, Entamoeba* etc.

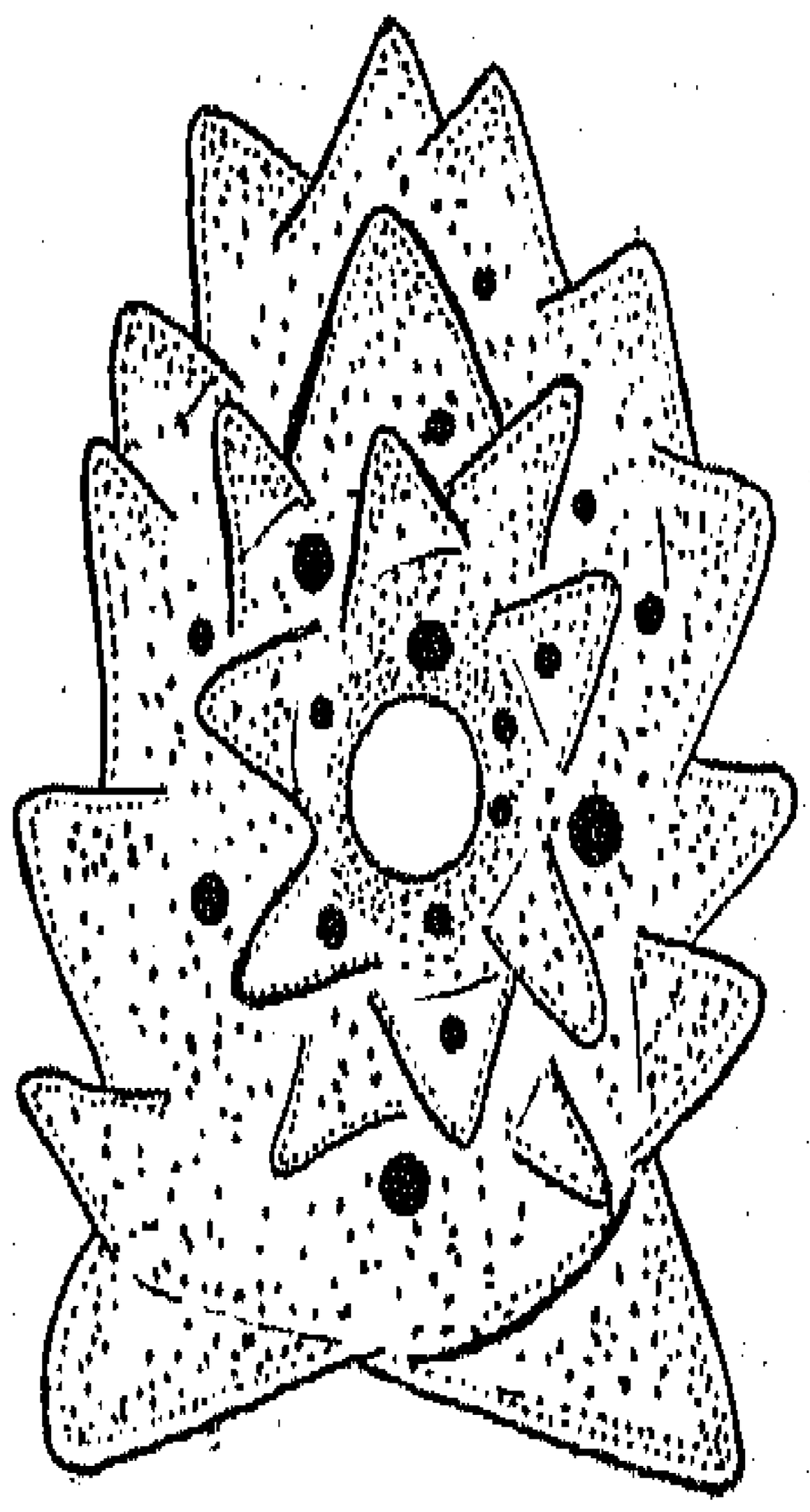

Fig. 36. Amoeba verrucosa.

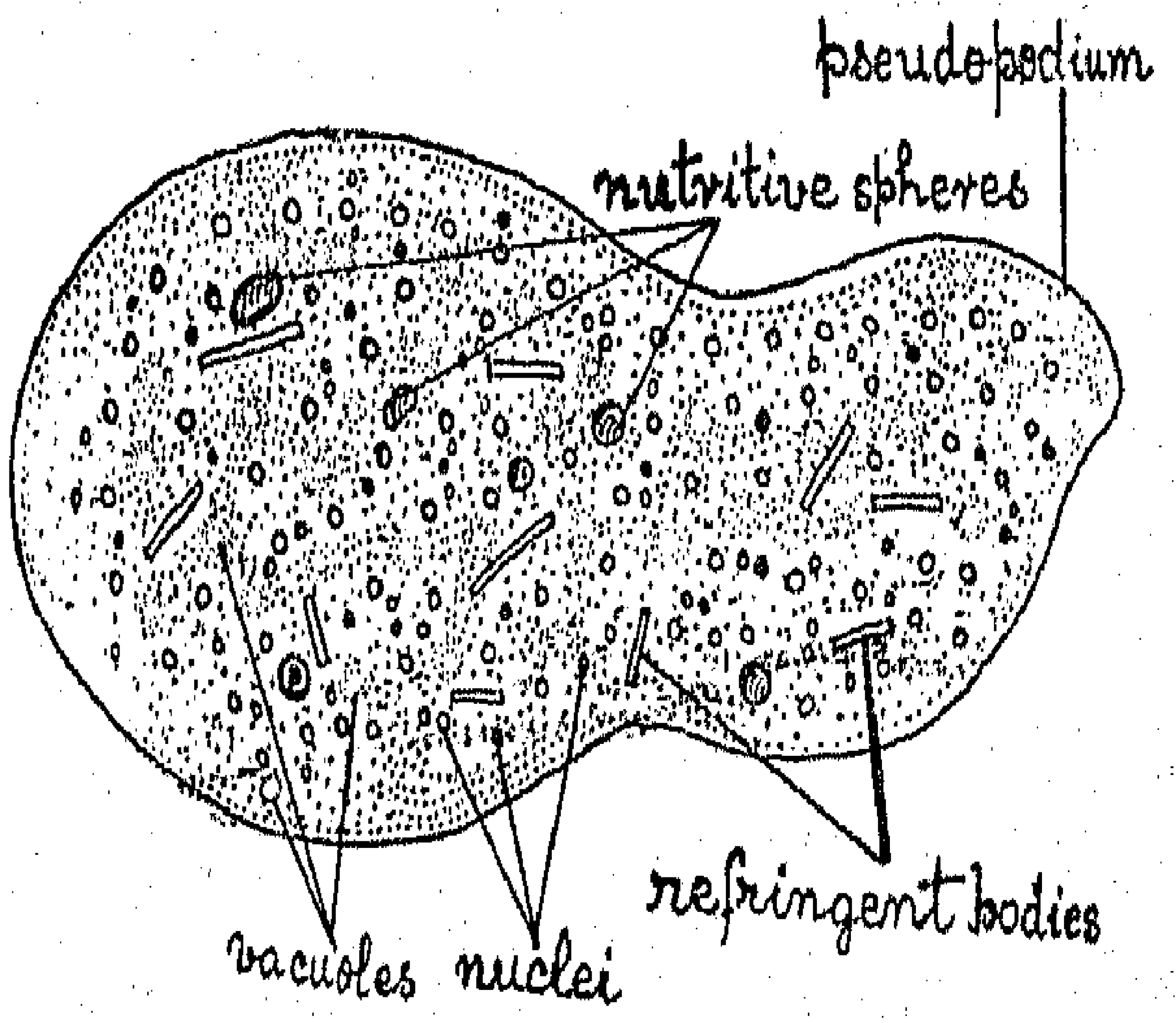

Fig. 37. Pelomyxa.

Entamoeba histolytica causes amoebic dysentery in man. *Pelomyxa* is a large multinucleate form which may have as many as one thousand nuclei ; it is found in muddy stagnant water.

Suborder (ii) **Thecamoeba** have a hard exoskeletal shell or thick test siliceous material. The pseudopodia are stout lobopodia. The forms are confined to fresh water. Are also known as testacea. The shell has one single opening the *mouth* or *pylome* through which the pseudopodia protrude out. One or more nuclei, food vacuoles and contractile vacuoles are found. Examples are *Difflugia* and *Arcella*.

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[1] [See page 93 of A text book of Invertebrate Zoology by Murli Manohar Saxena (1963 Edition) for a detailed description of all these kinds of pseudopodia.]

Difflugia is found in the **ooze** (a fine grained soft deep-sea deposit composed of shells and fragments of various organisms) at the bottom of fresh waters. A viscid substance is secreted on the surface of the animal on which foreign particles accumulate and in this manner a cylindrical or domelike shell is formed. There is a single nucleus and a terminal pylome through which pseudopodia protrude out. Reproduction occurs by binary fission and sometimes by multiple fission.

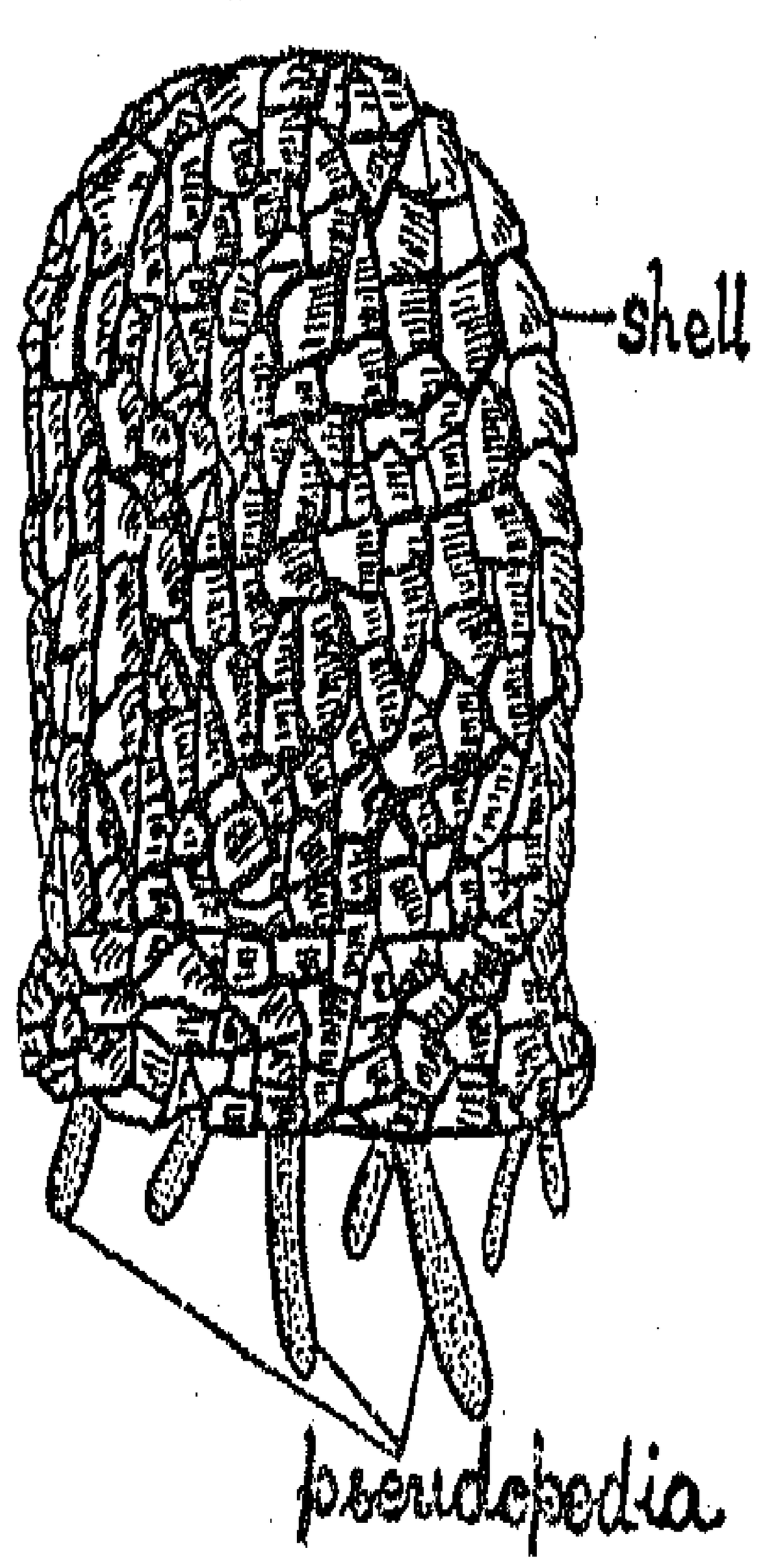

Fig. 38. Difflugia.

Arcella has a hollow hat shaped or cupshaped, chitinoid, transparent shell. The *pylome* or *mouth* is found on the lower surface through which the lobe like pseudopodia protrude out. The hat like shell floats in water upside down. In the chitinoid shell are arranged prismatic plates of a siliceous substance. The endoplasm contains two vesicular nuclei, a few contractile vacuoles and several food vacuoles. Reproduction occurs by binary fission. Budding also occurs. The animals are found in ooze and stagnant waters.

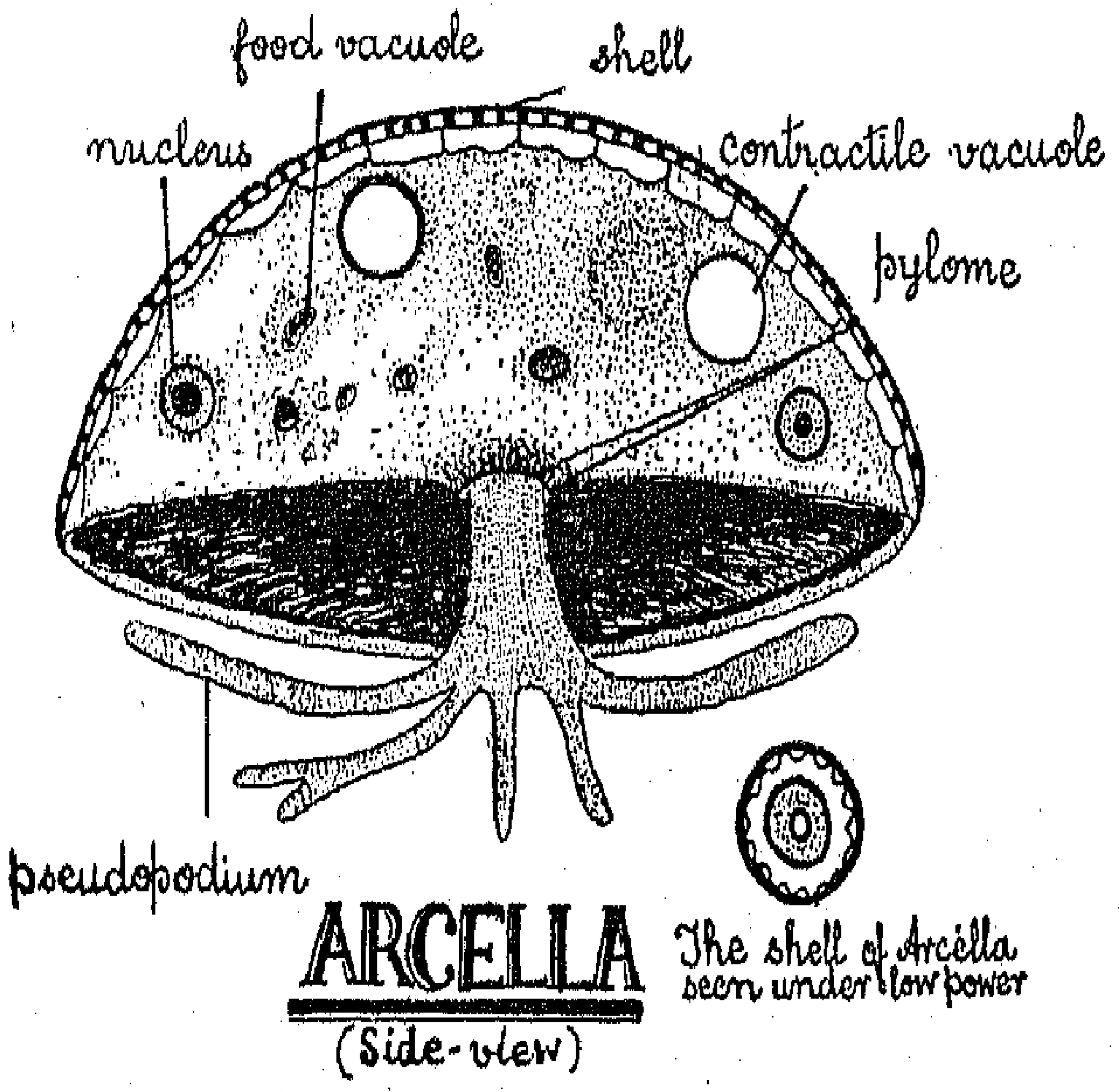

Fig. 39. Arcella (Side-view).

Order 2 **Foraminifera** includes marine shelled forms; the *shell* or *test* has numerous external pores. The shell is secreted by the animal itself and is made up of chitin or calcium carbonate; it is sometimes siliceous or gelatinous. The pseudopodia are very

fine needle-like which join at places to form a sort of reticulum or network, hence described as reticulose. The pseudopodia protrude out of the shell through pores.

When the shell has a single chamber it is known as **monothalamus** or **unilocular**; when it has many chambers it is called polythalamus or multilocular. Almost all advanced species exhibit **dimorphism** (When the individuals of a single organism exist in two morphologically completely distinct forms the phenomenon is known as dimorphism). Reproduction occurs by multiple fission and alternation of generations is very common. The Foraminifera are usually found crawling over the mud and ooze on the sea-bottom; they are sluggish in nature. The shell of these animals is formed of a special form of calcium carbonate known as calcite. The presence of Foraminifera indicates the presence of oil fields. Examples *Polystomella*, *Globigerina*.

Polystomella lives at bottom and has a hard translucent calcareous multilocular perforate shell. The various chambers communicate with each other by means of pores in the shell, thus the cytoplasm of the animal is continuous. Small pointed protoplasmic processes known as *retral processes* are found at the external ridge of the shell; needlelike pseudopodia protrude out, anastomose and form a reticulate arrangement. The pseudopodia are used chiefly for food capture and locomotion. The individuals of *Polystomella* occur under two distinct forms: (i) **macrospheric forms** which develop at a result of a process of copulation of gametes given off by the macrospheric form; are big in size, multinuclear with small nuclei, have a large number of chambers

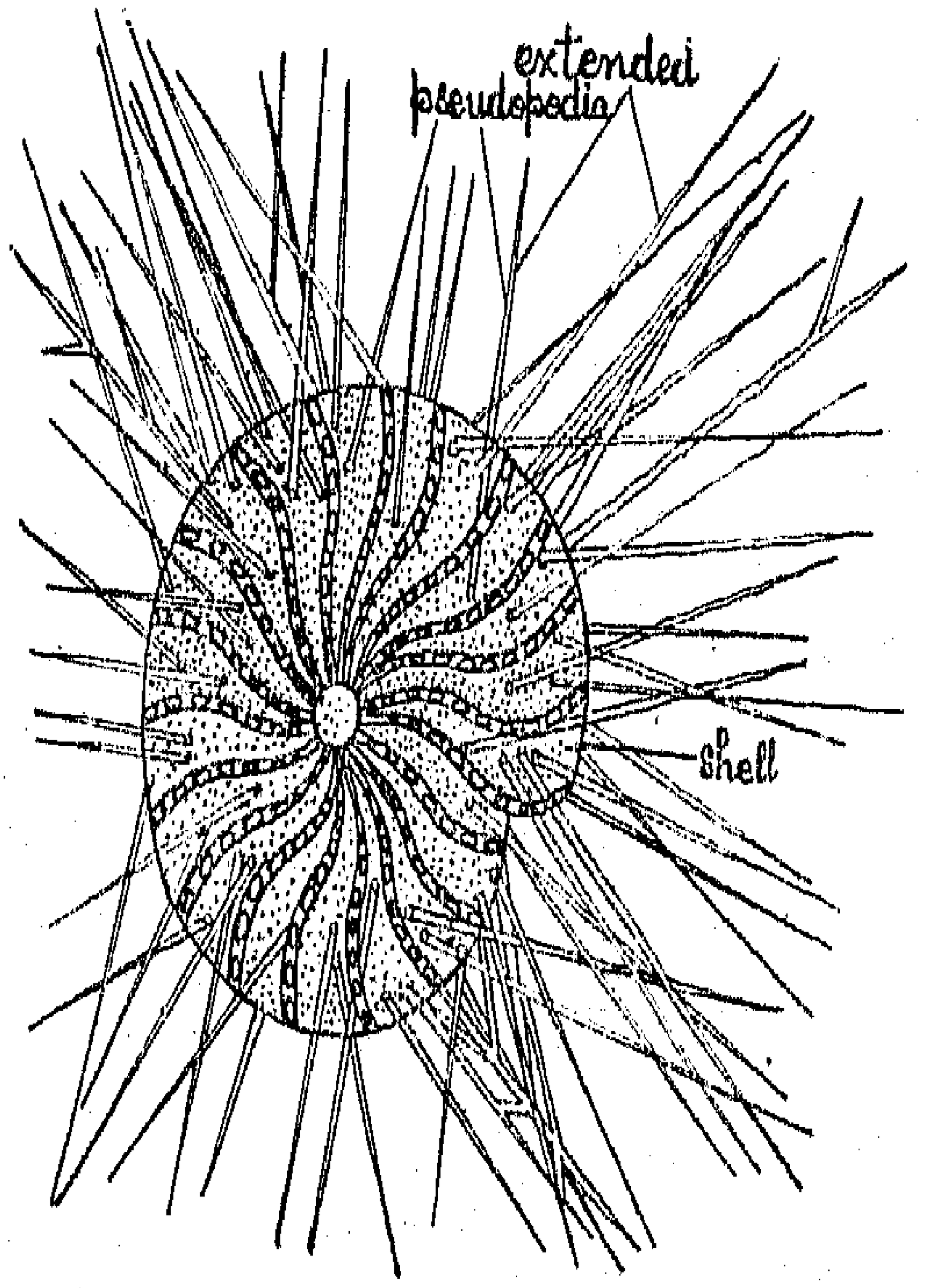

Fig. 40. Polystomella (living) (Megalospheric form)

of which central chamber is small; these are less abundant in nature; (ii) **macrospheric forms** which develop from the amoebulae formed by the microspheric form by schizogony, are smaller in size and have a smaller number of chambers than the microspheric form, the central chamber is large and they are more abundant in nature. When the animals die, their shells collect in the bottom which accumulate and form a sand known as ooze.

Globigerina occurs in Atlantic ocean, forms a large part of ooze. It is a pelagic form (found on the surface of water) and has only two to four chambers. Its shell is multilocular and perforate and the chambers are more or less spherical.

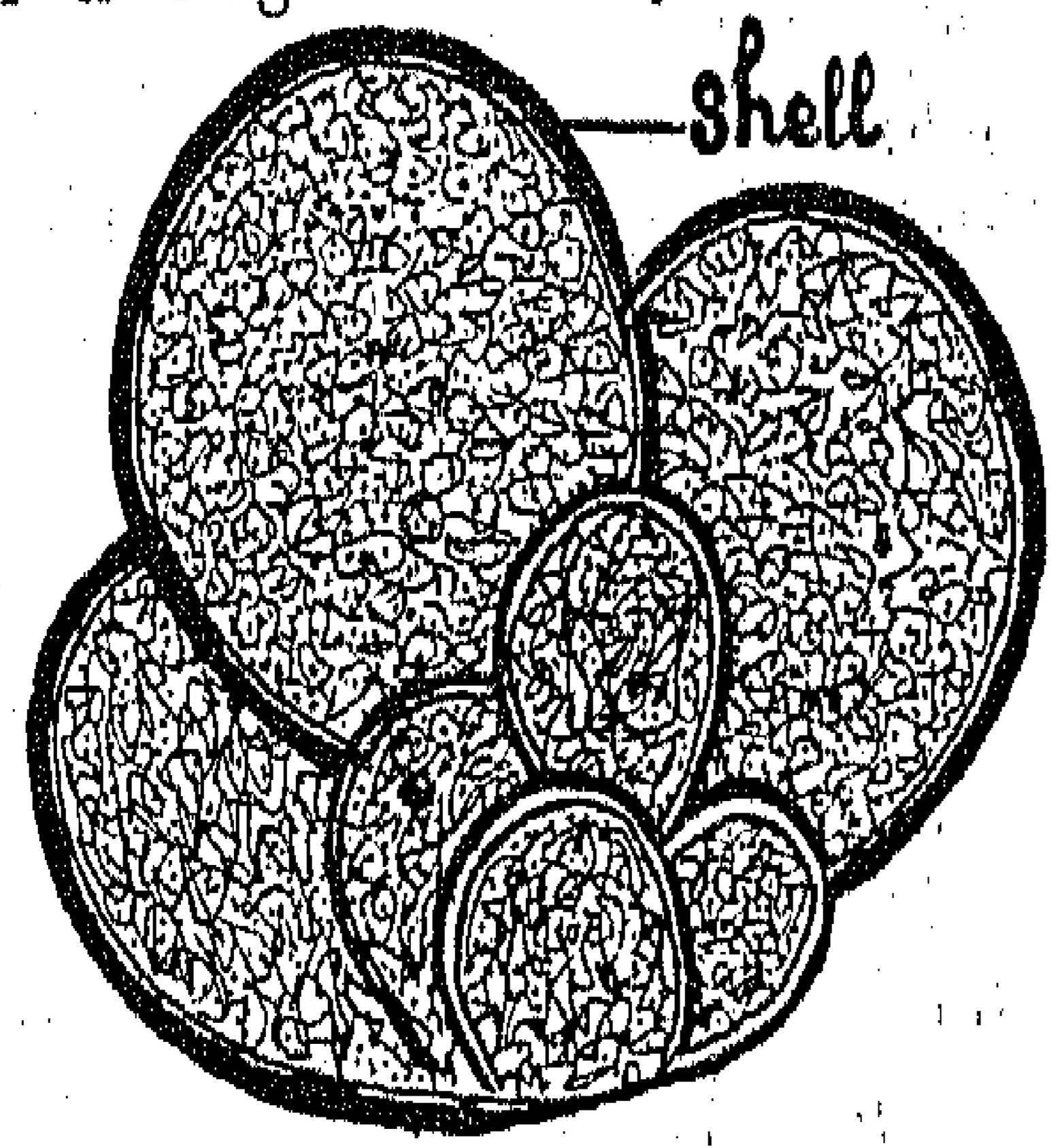

Fig. 41. Globigerina.

Order 3. **Heliozoa** *have a rounded body with radiating filamentous pseudopodia which do not anastomose; these pseudopodia called axopodia help in locomotion and food capture.* The axopodia are capable of bending movements and the animals perform a sort of rolling movement on their end points. By means of their vacuoles the animals can rise up or sink down in water. The body is more or less radially symmetrical and consists of an

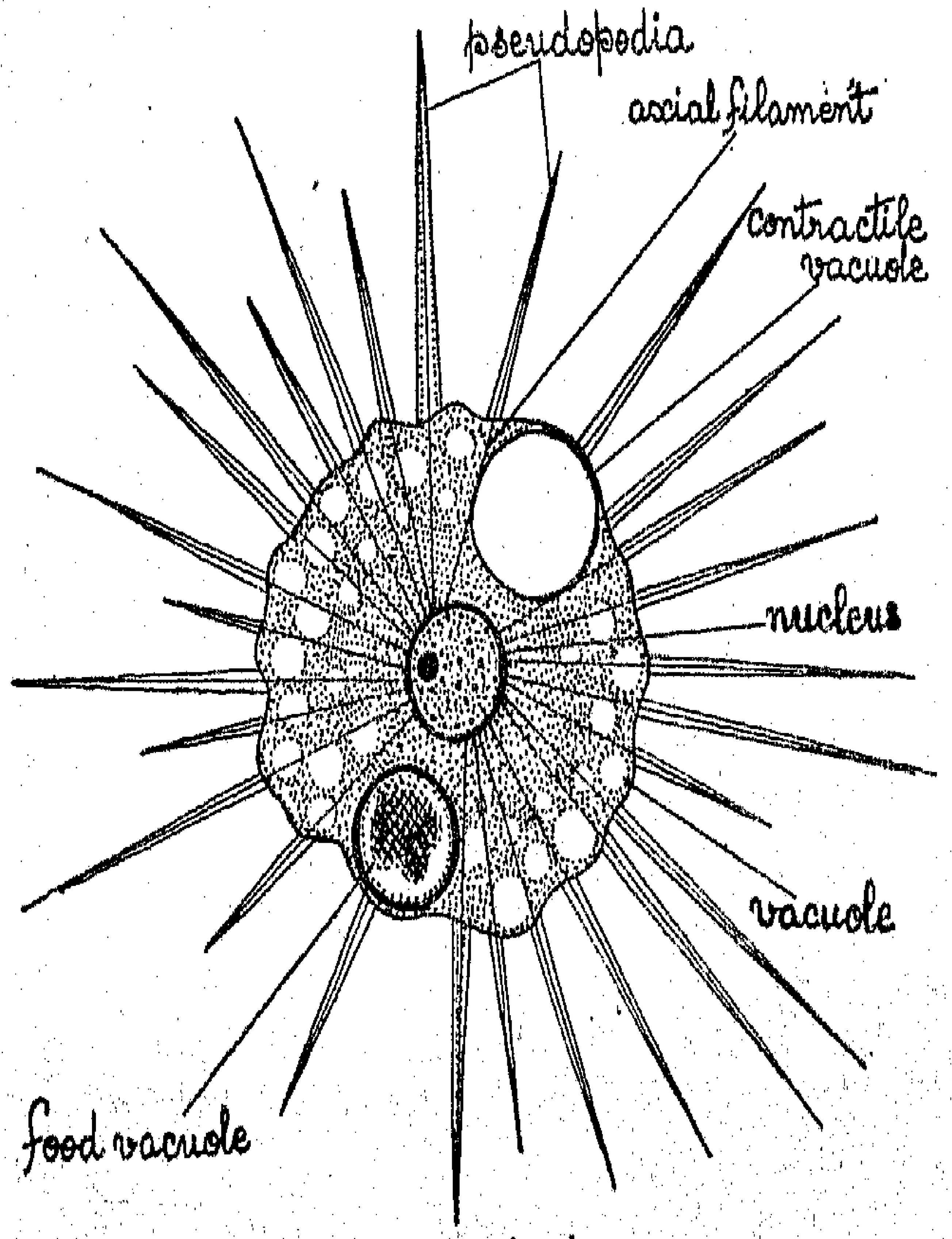

Fig. 42. Actinophrys

inner nonvacuolated *medullary part* and an outer alveolar *cortical layer* which forms the *ectoplasm*. Distinction between *ectoplasm* and *endoplasm* is clear. The endoplasm forms the medulla. The axopodia consist of a solid axial filament surrounded by a layer of thick liquid protoplasm. Nutrition is holozoic—various protozoa, algae, diatoms small crustaceans and rotifers forming the food. The touch of the pseudopodium paralyses the living prey probably due to a toxic secretion—thereafter it is transferred inside the cytoplasm where it is enclosed in a food vacuole and digested. Food-cups like amoeba are formed by some forms. Some of the Heliozoa have chitinous, siliceous or gelatinous *test* or *shell*. Reproduction occurs by *autogamy* or *paedogamy* [Autogamy implies syngamy or fusion of gametes derived by the division of a single nucleus]. Examples: *Actinophrys*, *Actinosphaerium*. *Actinophrys* also known as the Sunanimalcule is a shell-less uninucleate spherical organism. Of the many vacuoles in ectoplasm, one is contractile. The axial filaments of the axopodia travel through the ectoplasm and the endoplasm and reach the nuclear membrane. The pseudopodia do not branch and do not anastomose. The animal contains zoochlorellae. *Actinosphaerium* is also a freshwater form found amongst plants. It is a multinucleate form. The medulla and cortex are more distinct. The endoplasm has many nuclei and numerous small vacuoles. A few of the many vacuoles in the cortex are contractile. The endoplasm may have green symbiotic

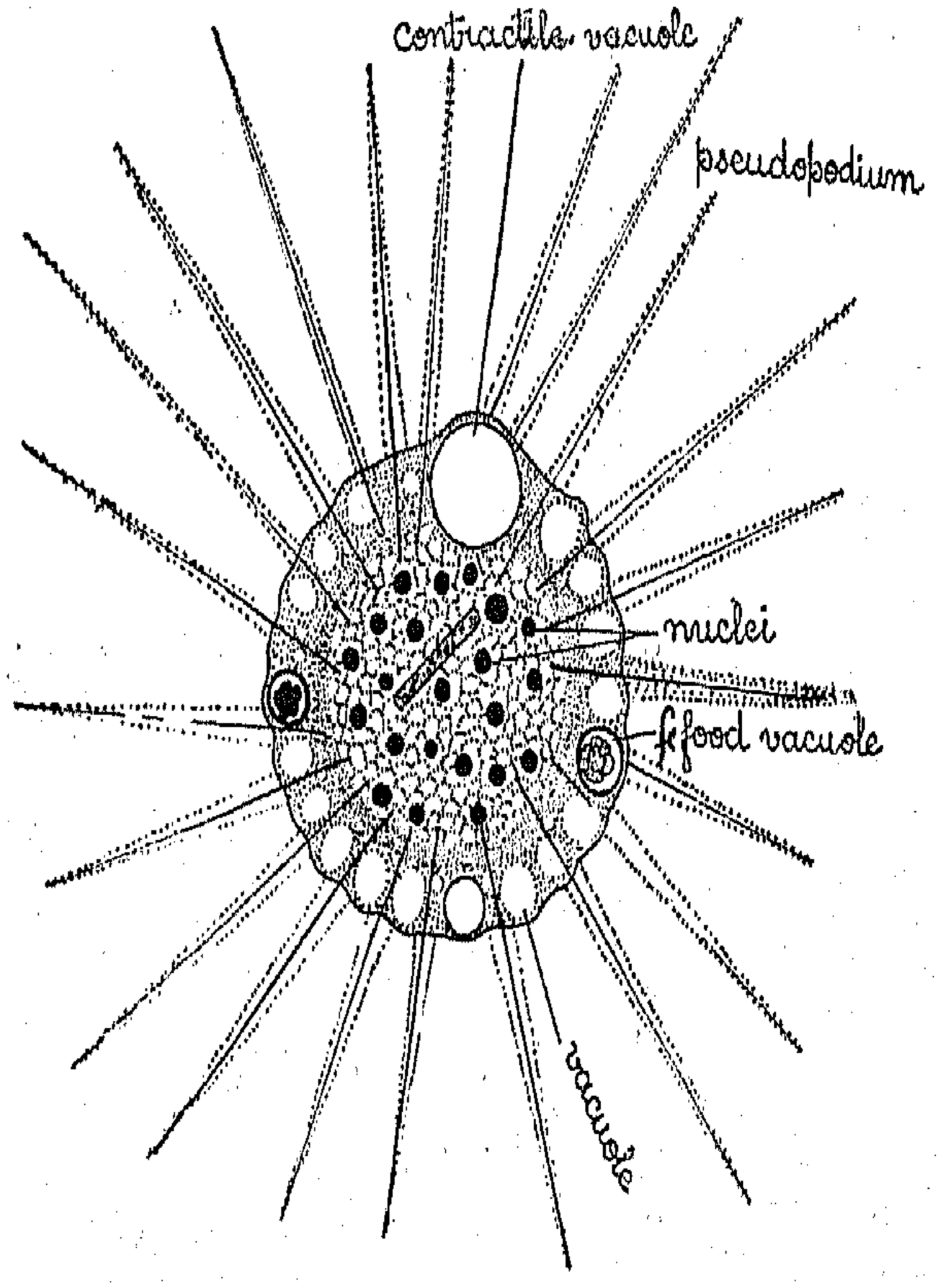

Fig. 43. Actinosphaerium (After various authors)

algae known as *zoochlorellae.* The axopodia do not reach the nuclei usually, they terminate in the ectoplasm. Reproduction occurs by an increase in the number of nuclei by mitotic divisions and thereafter plasmotomy occurs. *Paedogamy* also occurs.

Order 4. **Radiolaria** are all marine and reside mostly in the depths of the oceans. They usually possess a beautiful and complex siliceous skeleton. There are no contractile vacuoles; their outer layer of protoplasm is highly vacuolated. The pseudopodia are fine and radial and lack a conspicuous axial filament. A perforated membranous chitinoid *central capsule* lies imbedded in the cell body dividing into an inner or central **intracapsular region** containing the nucleus (or nuclei), oil drops, vacuoles, crystals and pigment and an extra-capsular region which may contain numerous vacuoles. The extracapsular region is divisible into three layers (i) the outermost *external layer* which sends out pseudopodia (ii) the middle *calymma* which is highly vacuolated and serves a hydrostatic function; it may have yellow symbiotic unicellular algae: the *zooxanthellae* which supply oxygen, starch and other food material to the protozoon which in turn supplies Co_2 and nitrogenous waste to the zooxanthellae. *Such a mutually beneficial association of two organisms is known as symbiosis.*

The body of radiolarian is typically spherical with more or less a radial symmetry. The pseudopodia are long filamentous, radiating, delicate and needle like. Nutrition is holozoic and the food consists of small protozoons, diatoms, copepods and minute algae. Reproduction occurs by binary fission. Example is *Thalassicola* in which there is no skeleton or it may be represented by siliceous spicules; there is only one nucleus: the extracapsular protoplasm has yellow cells (*zooxanthellae*).

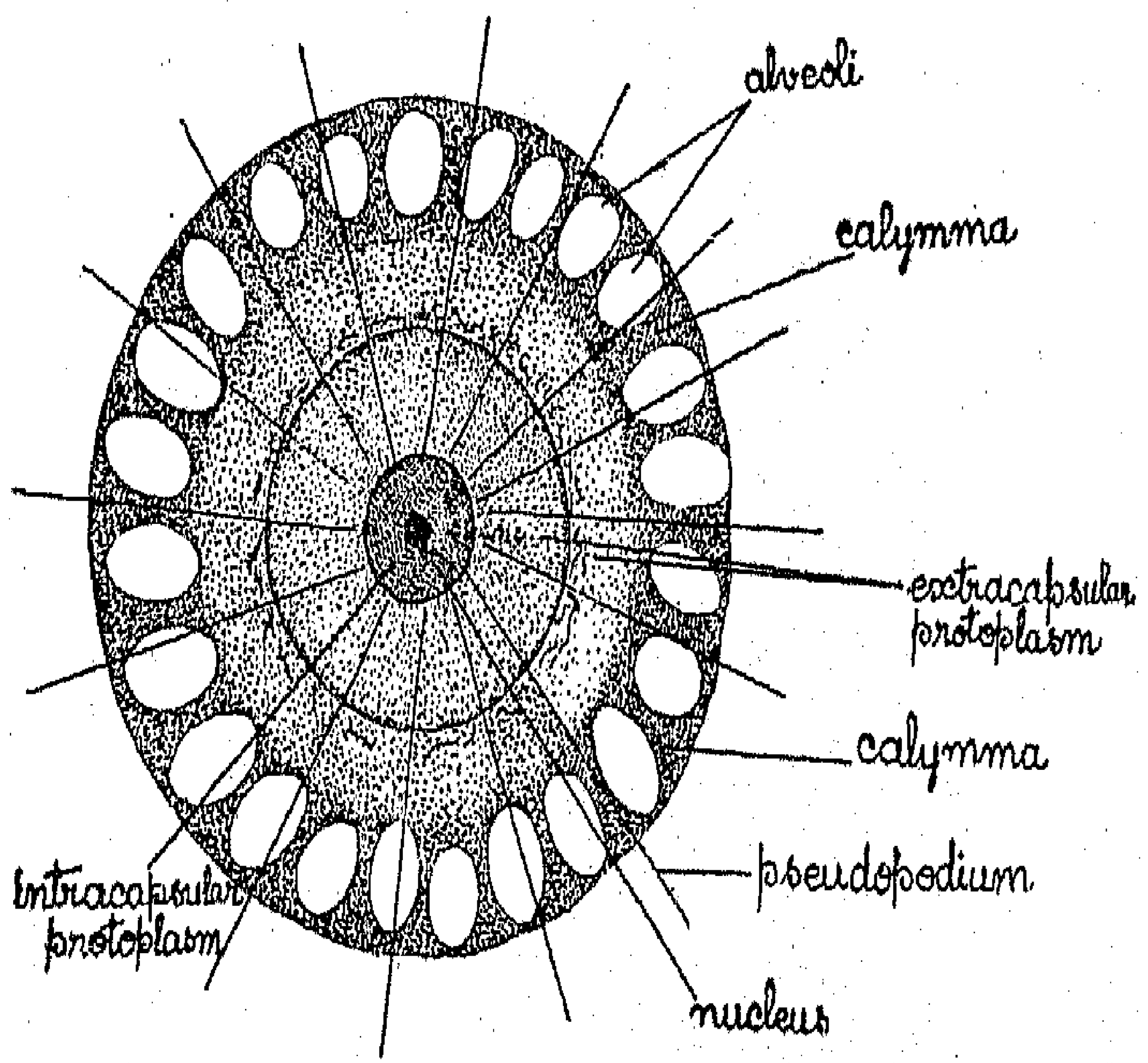

Fig. 44. Thalassicola (Diagrammatic).

Thalassicola is a marine pelagic form. The central capsule is capable of separate existence and from it the entire cell body can be regenerated.

Order 5. **Mycetozoa** are terrestrial and live in damp places. In their active phase they have no shell, skeleton or central capsule. In their quiescent phase, a cellulose cyst is however found. Numerous blunt pseudopodia are present. The *adult vegetative phase* is *plasmodial.* They form encrustations on rotten wood. Are distributed by air-borne spores. In the adult phase, the animals consist of a whitish or yellowish sheet of protoplasm in which are found thousands of small nuclei. Nutrition is holozoic.

Ex. *Didymum* which occurs on decaying organic leaves. *Plasmodiophora* is parasitic in the root cells of turnips, radishes etc., produces galls and causes 'root hernia'.

Class 3. **Sporozoa** *are exclusively parasitic protozoa with saprozoic nutrition and lack specialised locomotory organellae in the adult condition or the principal phase. At one stage of their life cycle they are intracellular. Only one nucleus is found, there being no meganucleus. Mouth, anal*

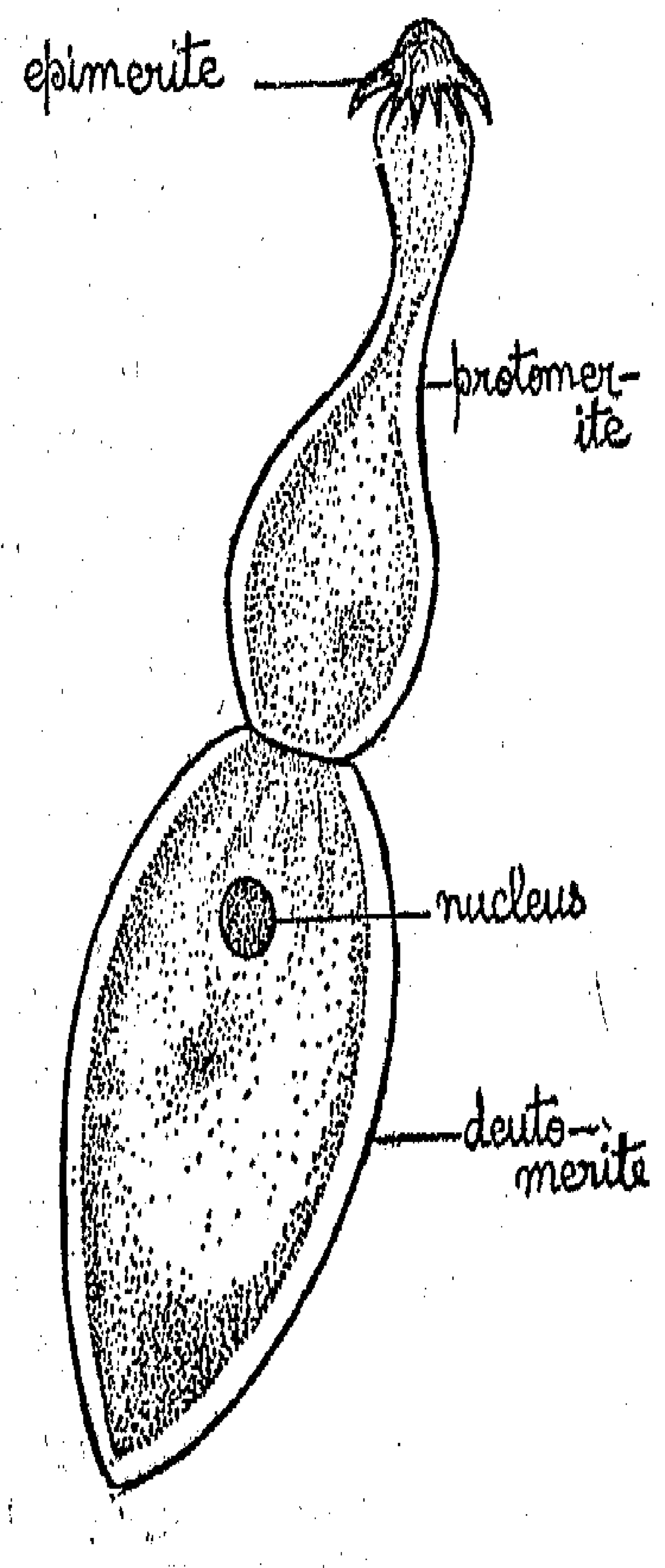

Fig. 45. Gregarina.
(A young trophozoite).

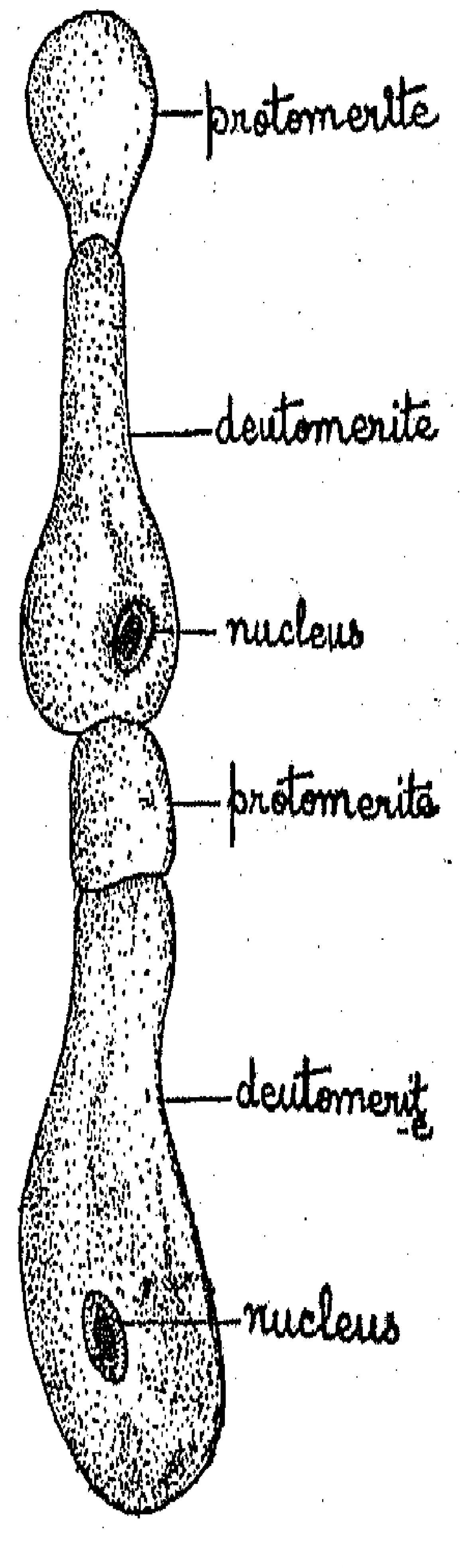

Fig. 46. Gregarina
showing syzygy.

opening or excretory pores are absent. Formation of resistant spores in plenty after the sexual processes (e. g. syngamy) is most characteristic of the entire group and hence the name Sporozoa.

The class is of great economic importance as it includes some of the important forms which cause diseases in man and domestic animals. Under this class we will deal with two orders only, omitting the detailed classification.

Order—**Gregarinidea** are nonpathogenic; the adult has only one nucleus, the adult trophozoite is an extracellular parasite (and also coelozoic) which is free and motile. Syzygy is common. Reproduction occurs mainly by sporogony which follows gametogony. The adult trophozoites act as gametocytes which associate in pairs and get enclosed in cysts. The isogamous (rarely anisogamous) gametes fuse and form nonmotile zygotes each of which becomes a **spore** and its contents divide to form **eight sporozoites** by three successive divisions. The forms are intestinal or coelomic parasites of invertebrates especially of Arthropods and Annelids. Examples are *Monocystis* and *Gregarina*. Both of these lack schizogony; the adult trophozoite has a stout cuticle, the ectoplasm contains myonemes. The body may be divided into three segments: (i) *epimerite* or fixing organ, (ii) *protomerite* and (iii) *deutomerite* which contains the nucleus; such a division of body is found in *Gregarina* but not in Monocystis. *Monocystis* is parasitic in seminal vesicles of earthworm. *Gregarina* is found in the alimentary canal of insects—grass hoppers, crickets etc. Life-cycle is completed in a single host. Syzygy is very common.

Order—**Haemosporidia** are true blood parasites; sporozoites are naked, the zygote is locomotory and is therefore known as *ookinete*. No zygote occurs. The trophozoite is amoeboid. Are intracellular parasites in the blood of higher vertebrates where schizogony occurs; sexual part of the life-cycle occurs in the invertebrate host. No part of the life-cycle is passed outside the host. The sporozoites are inoculated into the blood of the vertebrate host by the bite of the arthropod or the other invertebrate host in whose salivary glands the naked sporozoites are stored. Examples: *Plasmodium* (the malaria parasite of man. *P. falciparum* (most dangerous and fatal), *P. vivax* (causes Benign tertian), *P. malariae* (Quartan fever); transmission is effected by the female *Anopheles* mosquito.

Subphylum II **Ciliophora**, *Cilia are the organellae of locomotion and feeding. Nuclear dimorphism is found* (i. e. two kinds of nuclei are found). Are never amoeboid. The subphylum is divided into two classes:

Class 1. **Ciliata** *in which the adults always possess cilia. Suctorial tentacles are not found.* Mostly two nuclei are found: a *micronucleus* and a *meganucleus*. The body shape is definite with clear anterior and posterior ends. Myonemes, neurofibrils and contractile vacuoles are found. Usually have a well developed apparatus for obtaining nutriment and there may be found a *vestibule* (a depression often termed as *gullet*) leading to mouth. The inner part of the vestibule which often lacks cilia (as in *Paramecium* and *Vorticella*) is termed 'oesophagus'. The class is divided into two subclasses:

Subclass 1. **Protociliata** are intestinal parasites of amphibians, have a uniform covering of cilia arranged in longitudinal rows; there is no mouth or cytostome and nor a contractile vacuole. All nuclei are similar. Asexual reproduction occurs by plasmotomy and sexual reproduction occurs by gamete formation. Nutrition is saprozoic. Example is *Opalina*: a commensal in the large intestine of frog, has numerous nuclei evenly distributed in the endoplasm. Body oval and flattened; thin tough pellicle has longitudinally spiral grooves bearing cilia of equal length uniformly arranged all over the surface. Mouth and contractile vacuole absent. Asexual reproduction occurs by *plasmotomy*. Anisogamy occurs in sexual reproduction and zygotes are formed which after encystment may hatch out in the same host or may pass out with the faeces to be ingested by other tadpoles. The multinucleate adults developed, repeat the asexual cycle by plasmotomy in the adult frog.

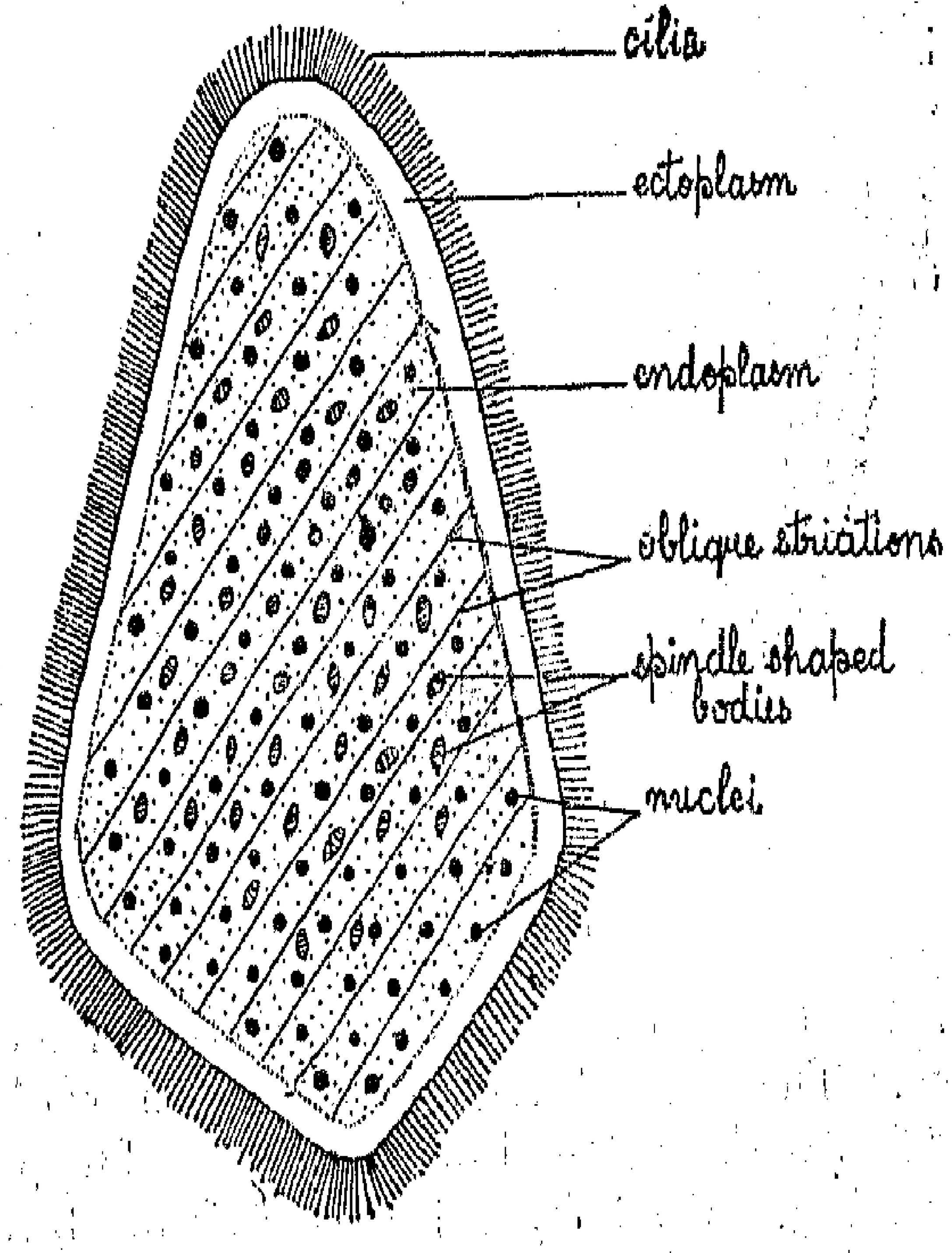

Fig. 47. Opalina.

Subclass 2. **Euciliata** are free-living, few are parasitic, mouth or cytostome and cytopharynx present; have nuclear dimorphism; one or more contractile vacuoles present; nutrition is holozoic. Asexual reproduction occurs by binary fission and sexual reproduction by conjugation. The subclass is divisible into a number of orders:

Order 1. **Holotricha** have uniform ciliation over the entire body. The body is covered with a pellicle. These are ciliates with a simple organisation. Some forms have trichocysts and some have undulating membranes. Example is *Paramecium* which has a peristome.

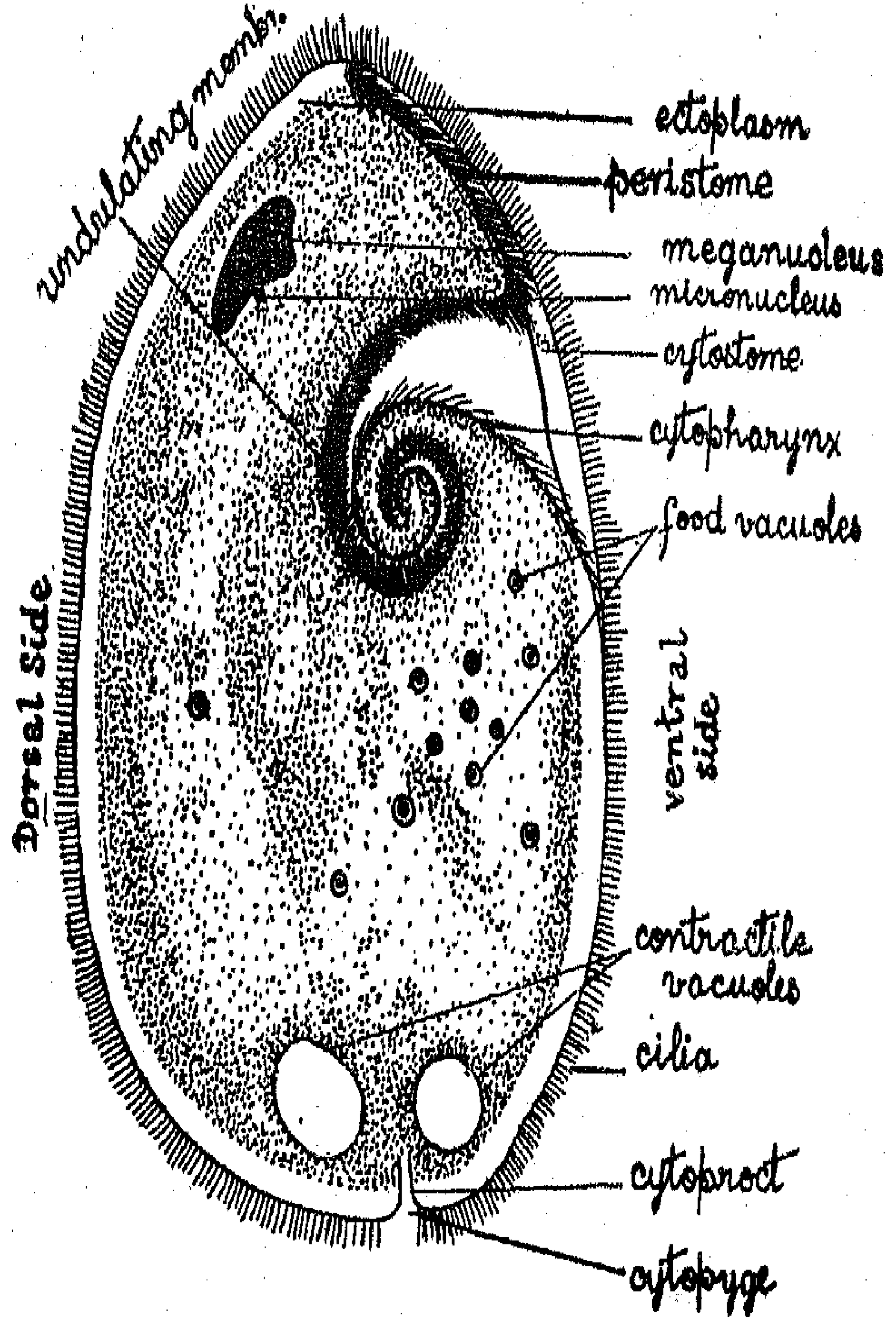

Fig. 48. Nyctotherus.

Order 2. **Spirotricha** have a gullet with an undulating membrane. The adoral reed of cilia is a clockwise spiral. Examples: *Nyctotherus* found in the rectum of frogs, toads and tadpoles of frog. The body is kidney shaped. It is parasitic in the rectum of frogs as well as the intestine of man. Its cytopharynx is long and coiled and has an undulating membrane. A large macronucleus, a small micronucleus and two contractile vacuoles are found. At the posterior end there is a *cytopyge,* a sort of anal opening with which probably the contractile vacuole communicates. *Balantidium* is also parasitic in the rectum of frogs and the intestine of man where it is often harmful. *Balantidium coli* is found in the colon and caecum of man and causes **balantidial dysentery**. The body is oval in shape and has a *meganucleus* and a *micronucleus.*

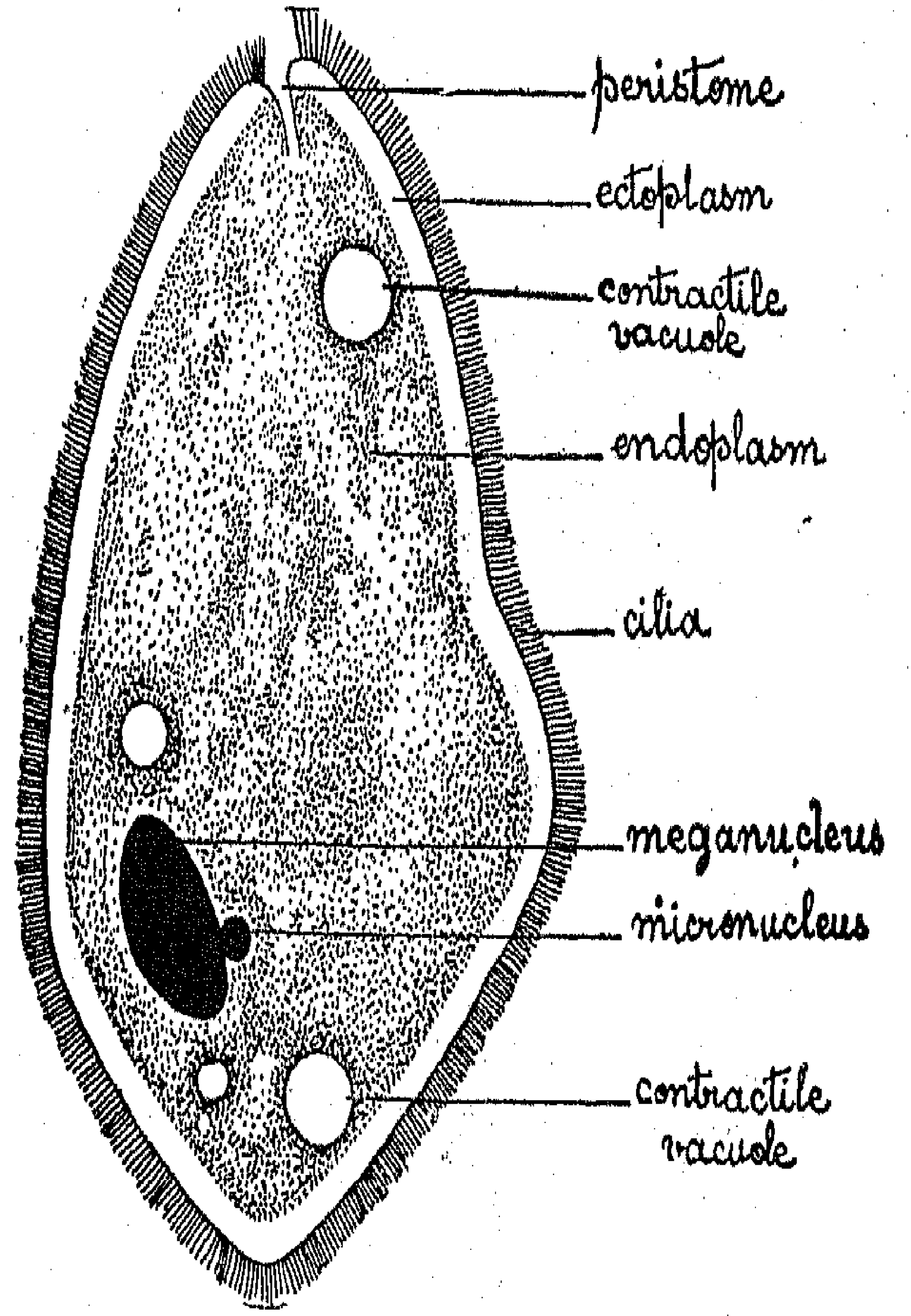

Fig. 49. Balantidium.

Order 3. **Peritricha** remain for the most part permanently fixed by the aboral surface. The gullet is permanently open and has an undulating membrane. The cilia are found only in the aboral ring and the rest of body bears no cilia. The body is vase or bell shaped. At the aboral end (away from mouth) there may be present an organelle of attachment—the **stalk.** Example: *Vorticella* which is like a solid inverted bell. It is a solitary form occurring in fresh waters. Certain species are marine. The stalk is contractile due to myonemes. It is spirally contractile. The edge of the peristome is thickened and forms a projecting rim. Inside this rim is an elevated disc. Between the rim and the disc lies the *mouth* which leads into the vestibule. The vestibule leads into the gullet or *cytopharynx.* The *macronucleus* is long, curved and band like; a small *micronucleus* lies close to the macronucleus. One (rarely two) contractile vacuole, cytopharynx, numerous food vacuoles, distinct ectoplasm and endoplasm are found. Nutrition is holozoic. Asexual reproduction occurs by binary fission and sexual reproduction occurs by conjugation.

Class 4. **Suctoria** *in which the adults mostly do not have cilia but instead possess one or more suctorial tentacles,* which help in feeding, in catching prey and absorbing food. With a few exceptions, all are sessile. A few are endoparasitic. Reproduction occurs by formation of buds which may be external (as in *Ephelota*) or internal i. e. endogenous budding as in *Acineta.*) *Ephelota* is a marine stalked form and has knobbed tentacles. Meganucleus is much branched. The buds are produced on the upper surface. Extensions of nucleus are found in the buds. The buds become detached, acquire cilia on one surface and swim away. The cilia are lost and the tentacles develop. For nutrition, a hole is made on the body of the host by the pointed tentacle, the juice is sucked into the body. Nutrition is *holozoic* i. e. the tissues are taken as such into the body of the protozoon. *Acineta* is a stalked form, the stalk expands to form a shallow cup. Reproduction occurs by internal budding. The buds sink in a depression which becomes a closed *brood-cavity* in which the buds assume cilia and form ciliated larvae which eventually escape and swim away. The larvae become transformed into adults. It is both fresh water and marine.

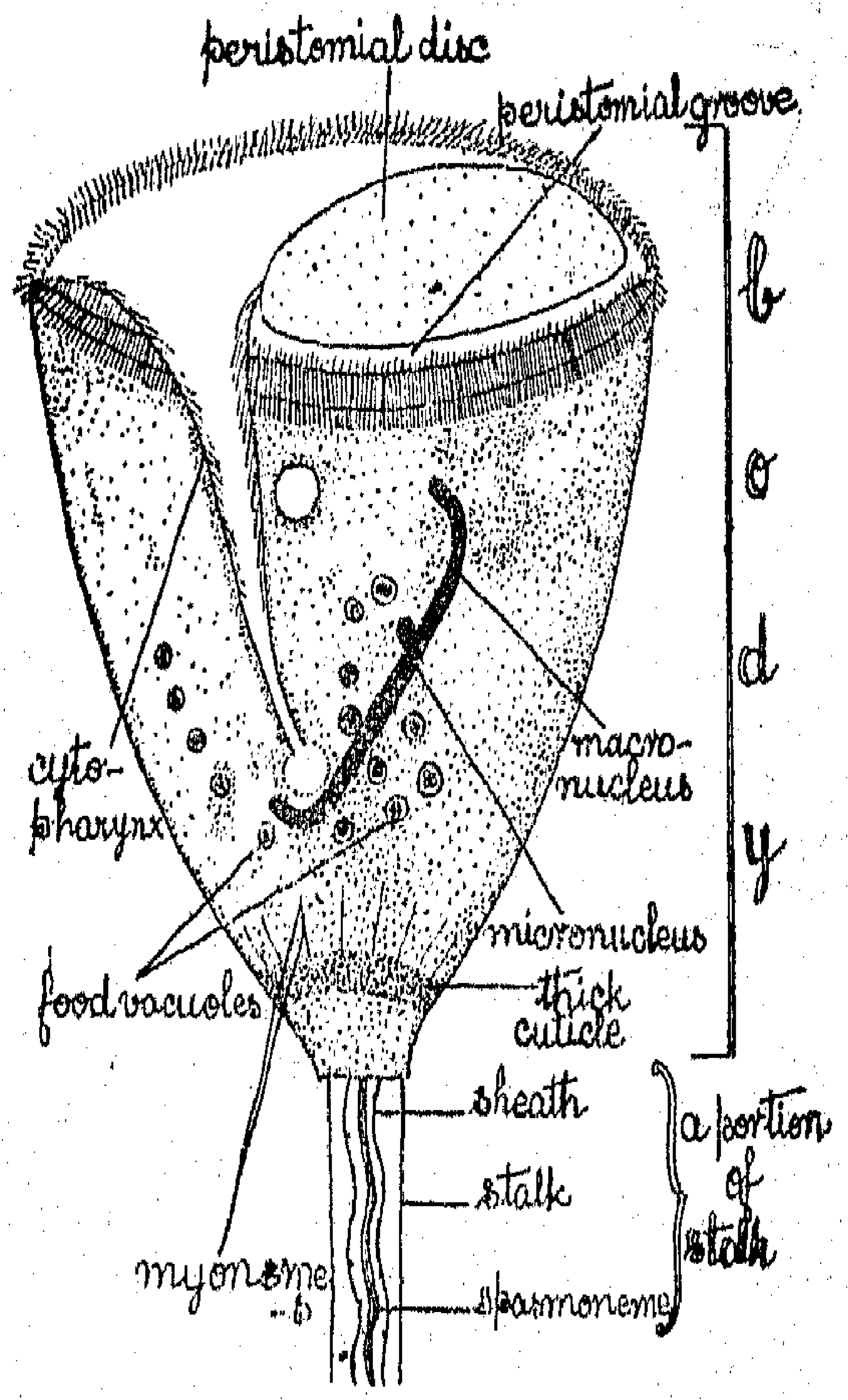

Fig. 50. Vorticella, a diagrammatic sketch.

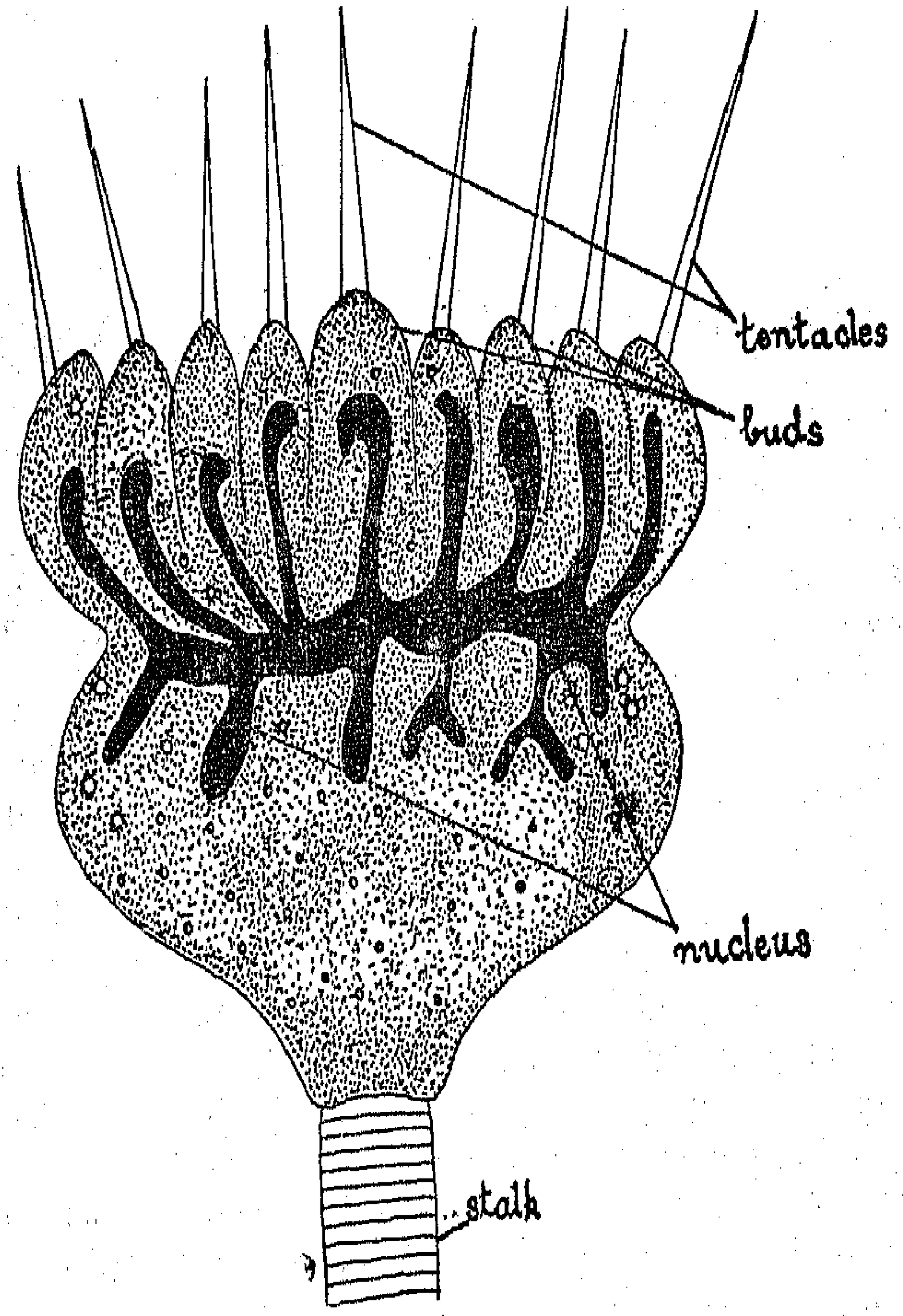

Fig. 51. Ephelota (After Hertwig).

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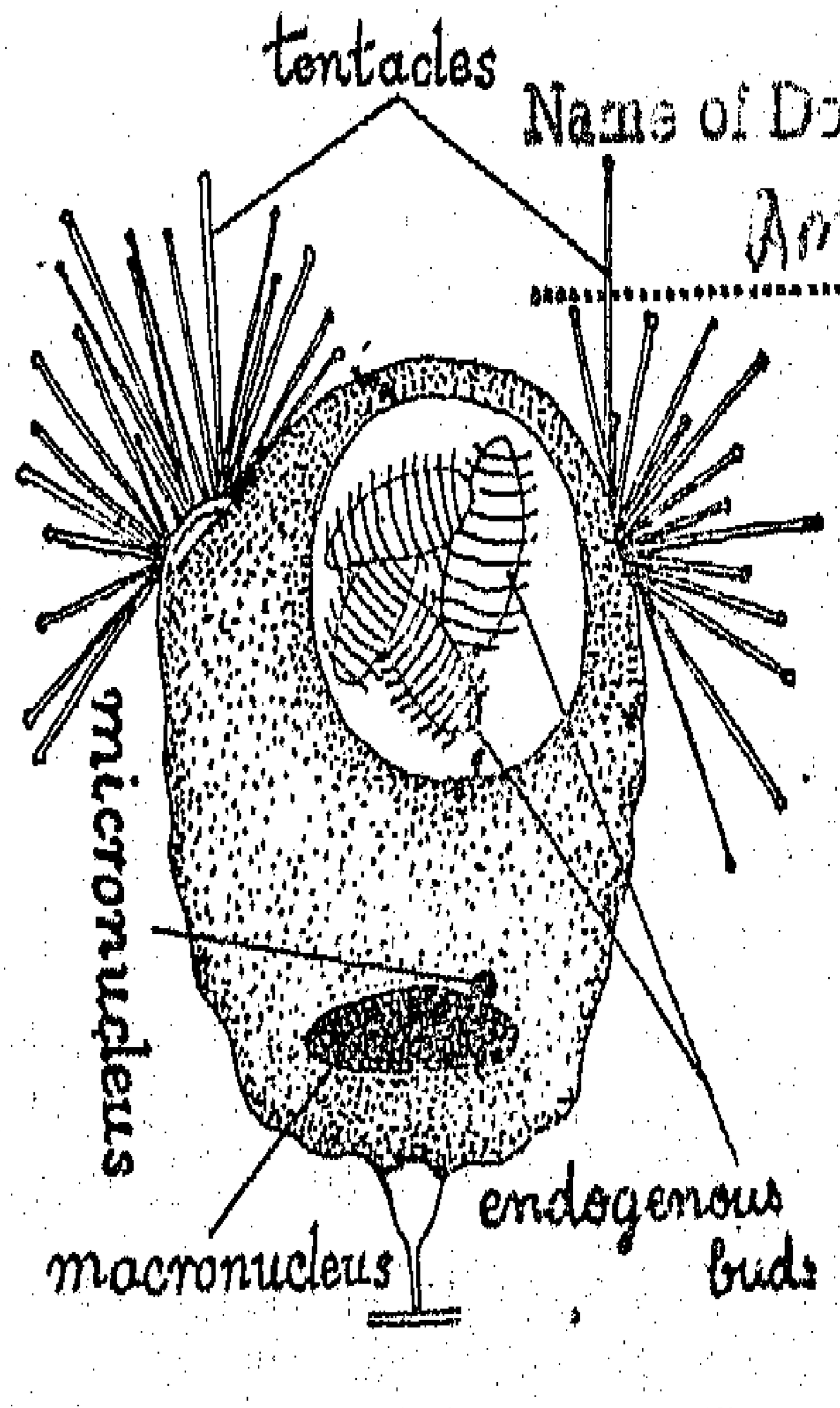

Fig. 52. Acineta (After Butschli).

5

Structure and Physiology of Amoeba

Give an account of the structure and physiology of Amoeba and show how it explains the basic principles of Zoology. (Agra, 1951)

Amoeba is a microscopic organism with an irregular shape and transparent body. In nature it is quite abundant amidst the great variety of other microscopic organisms in the slimy deposit at the bottom of ponds of rain-water or other freshwater ponds and streams. *Amoeba* keeps changing its shape constantly and slowly progresses in a direction. The speck of complex matter which constitutes amoeba's body is *protoplasm* and though minute, amoeba clearly manifests fascinating phenomena of life: spontaneous locomotion, feeding, growth, reproduction and irritability or sensitiveness to changes of environment and other stimuli. The fact of independent and isolated existence in life of such a small fragment of this complex aggregate of matter endowed with life makes amoeba an interesting object of detailed study, for: an inquiry into its structure and physiology becomes to a very great extent an inquiry into the structure and physiology of the protoplasm itself.

The constant changes in shape and position are effected by pushing out protoplasmic projections or processes called *pseudopodia* which alter in size and shape, some new processes being formed, the others being withdrawn simultaneously. A streaming motion of the protoplasm of *Amoeba* also occurs at the same time—a series of such streaming movements in succession cause an extremely slow progression.

The finger-like protoplasmic projections which are formed and then withdrawn are known as *pseudopodia* (*pseudos*, false, *podos*, feet) and are chief locomotory organellae. An *extremely* thin semipermeable elastic protoplasmic membrane *plasmalemma* forms the outermost surface of Amoeba's body; *it* exercises a control on the entrance into and exit from the body of amoeba, of various substances. The protoplasm inside is in a colloidal condition and cannot therefore pass out into water through the permeable membrane. Plasmalemma is insoluble in water.

The protoplasm is divisible into two regions (i) the *nucleoplasm* which constitute the nucleus and (ii) the *cytoplasm* which lies between the nucleus and the plasma membrane. The nucleus is disc-like, biconcave, oval or spheroidal and may lie anywhere in

the endoplasm, near the centre of the body, sometimes seen near the tip of a projecting pseudopod and then shifting back to its position. A strong delicate *nuclear membrane* surrounds the nucleus. When the nucleus is about to enter the reproductive phase, two rounded bodies: *nucleoli* appear in it. The nucleoprotein of nucleoli is distinct from other parts of the nucleus. In the peripheral region of the nucleus is found a ring of chromatin granules or blocks. The nucleus controls all the metabolic activities of amoeba. It undergoes remarkable changes during reproduction. In the non-reproductive phase, the nucleus controls digestion. When Amoeba is cut into two parts, the enucleated part is incapable of regenerating the parts lost and dies ultimately. The nucleated part continues all activities and behaves as a normal amoeba; it regenerates the lost parts. It follows therefore that *nucleus is absolutely essential for the normal life of amoeba, for growth, regeneration and reproduction; it is indispensable for metabolic activities and is primarily responsible for the control of anabolic activities.* A nucleus alone without cytoplasm is incapable of independent survival, in case it is isolated. Nucleus is the carrier of hereditary factors also.

In **cytoplasm**, the outer colourless homogeneous glassy looking layer is the *ectoplasm* while the inner more fluid and more granular part is the *endoplasm*. The outer stiffer and gelated, more solid portion of endoplasm is the *plasmagel* and the central more fluid larger portion of endoplasm is the plasmasol. The *plasmagel* and *plasmasol* are mutually interchangeable and really represent two physical states of the same substance, the *endoplasm*. The endoplasm has imbedded in the plasmasol, a *contractile vacuole* and numerous *food vacuoles* besides the nucleus; besides, the endoplasm contains numerous crystals, oil globules and foreign bodies such as sand particles etc. The contractile vacuole keeps pulsating and by expelling water to the exterior (the excess water which enters amoeba's body by endosmosis), it controls the water-content of amoeba's body and is thus *osmoregulatory* in function. When it bursts the plasmalemma is ruptured and the water is ejected out. Water is actually secreted by the protoplasm into the contractile vacuole. Contractile vacuole is also indispensable for amoeba's life for in its absence, amoeba's body would burst due to excess of water which is constantly entering its body.

Amoeba's food is formed by minute organism: algae, small living protozoans: flagellates and ciliates, paramecia etc., rotifers and bacteria etc. The food can be ingested anywhere on the body surface by means of pseudopodia. When food is taken it is accommodated inside the cytoplasm in a small temporary space termed as the *food vacuole*. Food vacuoles are formed in quite a large number; their position is not fixed in the body. Once formed, the food vacuole persists until its food-content is completely digested and absorbed and the undigested residue is egested out which may be done anywhere on the body surface. No anus is found, and nor there is any fixed spot for egestion.

Locomotion—The movement of amoeba is known as amoeboid movement and comprises a movement in space as well as a simultaneous change of the bodyshape by the formation of protoplasmic projections or *pseudopodia.* The amoeboid movement is secured mainly by the formation of pseudopodia which are temporary finger like protoplasmic processes. The body has no fixed anterior and posterior ends. The movement is so slow that it can be detected only under microscope. The direction of movement is also not fixed. The locomotion of amoeba has been a subject of study and wide contemplation by many zoologists since 1830 and several theories have been propounded but **'the change or viscosity theory'** or the **'sol-gel theory'** of **Mast** is most widely accepted. There are two physical states of endoplasm (i) '*gel' state* in which the particles come close together and (ii) '*sol' state* in which the particles of endoplasm move apart. According to **Mast**, the plasmasol can transform itself into plasmagel and the plasmagel can change into plasmasol.

The gelation and solation occur one after another in regions and in succession as follows: (i) Amoeba first ceases to float and attaches to a substratum (ii) gelation of the plasmasol occurs at the anterior end or the end towards which the amoeba is advancing (let this end be for the time being called the anterior end) (iii) solation of the plasmagel occurs at the posterior end and (iv) in the fourth stage, the plasmagel at the posterior end contracts. In the pseudopodium, the plasmasol flows forward and soon the margin of his pseudopodium becomes gelated. A tube is formed whose walls are made of plasmagel and inside which is the plasmasol. The forward flow of the plasmasol continues and serves to push the tip of the advancing pseudopodium forwards. In the posterior region the plasmagel is continually being transformed into plasmosal which flows forwards in the projecting pseudopodium by the contraction of the plasmagel tube in the posterior region or the region of solation. The repeated succession of these four incidents causes forward movement of amoeba. In some forms one pseudopodium is formed in one direction only. In others (*A. proteus*) where numerous pseudopodia are formed, one of them predominates all others and it alone causes movements.

Nutrition is holozoic, i.e. it ingests solid food consisting of other minute organisms like small acquatic plants e.g. *oscillaria* and diatoms, bacteria etc.; amongst the protozoa ciliates and flagellates are eaten. The various processes in the holozoic nutrition are *ingestion, digestion, assimilation* and *egestion.* Food ingestion can occur at any point on the body for there is no mouth nor any point fixed for the process. Ingestion can occur by any one of the four processes (i) *import* (ii) *circumfluence* (iii) *circumvallation* and (iv) *invagination.* After ingestion the living prey is paralysed and killed by mere contact with amoeba's body and then it is enclosed in a *food vacuole* along with a drop of water. The wall of food vacuole is a semipermeable and probably solid membrane.

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constantly enters its body by osmosis through the semipermeable membrane. This water is excreted into the contractile vacuole and is extruded out. Thus in fresh water amoebae, the contractile vacuole performs the function of osmo-regulation. The contractile vacuole is not found in marine protozoa. In parasitic forms also it is not found. The phase of growth of contractile vacuole is known as **diastole** while its collapse is known as **systole** in which it discharges its contents to the exterior and disappears for a moment. Next moment a fresh vacuole is formed which grows in diastole.

Irritability is the property by which the living organisms respond to external stimuli. **Behaviour** signifies the sum total of all activities of an animal. *Amoeba* lacks specialised receptors or sense organs nor it has specialised organelles of co-ordination and nor any effector organellae. The protoplasm of amoeba's body is sensitive, *sensitivity* being the innate property of all protoplasm. Amoeba responds to various stimuli due to the general property of *irritability* of protoplasm. Not even a trace of nervous system is found. Amoeba reacts positively to a weak mechanical stimulus and negatively to a strong mechanical stimulus. Reaction to mechanical stimulus is known as **thigmotropism** or **thigmotaxis.** *Amoeba* moves towards a weak light thus showing *positive phototropism* to a weak light. It moves away from a strong light and is therefore *negatively phototropic* to a strong light. Amoeba shows a negative chaemotaxis to substances like KOH and NaCl. *Amoeba* moves towards food particles due to *positive chaemotaxis.* Optimum temperature for amoeba ranges from 20° to 24°C; it dies in the temperature range 30° to 35°C. It shows a negative reaction to hot water as well as excessively cold water. *Galvanotaxis* is negative, amoebae proceed towards cathode when an electric current is passed through the water containing amoebae. In a strong electric current, the body of amoeba disintegrates. Geotropism is positive and the amoebae are found attached at the bottom of the container. **Rheotropism** is positive, the amoebae tend to come in line with the water current.

There is certainly a sort of conductivity present in the cytoplasm itself, for the plasmalemma receives the stimuli and transfers them to the plasmasol. This is known as internal irritability. A beginning of 'conduction' is thus clearly manifested in amoeba.

Reproduction: Amoeba reproduces asexually by *binary fission* in which mitosis occurs, which involves mitotic changes; *prophase, metaphase, anaphase* and *telophase* occurs accompanied by distinct morphological changes. In *Amoeba proteus* another method of reproduction is **sporulation without encystment.** Small granules of chromatin blocks or *chromidia* occur in the periphery of the nucleus; these escape into the endoplasm by dissolution of the nuclear membrane at places, each of these chromatin blocks develops into a nucleus with a nuclear membrane around it; these nuclei known as *amoebulae* develop spore cases, the parent body shrivels up and the parent nucleus is used up. Large number of these spores formed in a single amoeba sink to the bottom on being set free. These are capable of tiding over unfavourable conditions and each one of them forms an amoeba on return of favourable conditions.

Amoeba explains the basic principles of Zoology; it shows all the vital activities which characterise the higher forms of life and which form the subject-matter of Zoology. Amoeba's structure gives sufficient clue to the structure of a cell which is the unit constituting the multicellular body. The fundamental elements of cytology are thus revealed. Its physiology including the modes of locomotion, feeding, growth, reproduction, respiration, excretion, osmoregulation, irritability and self-protection etc., gives valuable clue to the fundamentals of similar activities found in other members of the animal kingdom. Food is ingested, enzymes are produced to digest it; the process denotes a starting point in the same direction which will take us to the complexities of nutrition and digestion in higher forms. Nutrition leads to growth of the body by additions made in the cytoplasm by assimilation; the same is true of other forms and the fact is a basic principle of Zoology. On attaining a maximum size characteristic of the species, no growth occurs but instead, the surplus energy is utilised in the 'maintenance of the race'; this is another basic principle of Zoology. Likewise, all the activities of amoeba are simply in line with those found in other animals. Of course, amoeba is a very lowly organized and simple form of life but as far as the basic principles are concerned, 'a good deal of clue' is afforded by the structure and physiology of this fascinating creature. Respiration including the oxidation reactions after the intake of oxygen resulting in the release of energy is the same in principle in amoeba as in other animals. *Anabolism* and *Katabolism* or the physiological burning,—the two great principles of Zoology are unfolded. The basis of all reproduction is cell-division and that is revealed by amoeba in its very simple form. Keeping in view the entire structure and physiology of amoeba, one would not be wrong to state that amoeba does introduce us to many of the fundamental principles of Zoology.

6

The Amoeboid Movement

Amoeboid means something that changes every now and then. (Greek *amoibe* means *change*). '*Amoeboid movement*' implies irregular movement with no fixed direction of progression of the organism; such a movement is characteristic of many protozoan forms and occurs by formation of blunt cytoplasmic projections known as *pseudopodia* which are given out and withdrawn and again replaced by fresh ones. The pseudopodia may form anywhere on the surface of the body and hence the direction of progression varies constantly. The cytoplasm itself moves into the pseudopodia. The shape of the animals exhibiting amoeboid movements is not at all fixed due to complete absence of a firm shape-giving pellicle. The movement is very slow. It represents a very primitive type of animal locomotion. The amoeboid movement is probably due to the inherent power of contractility in the unspecialised protoplasm itself and is typically exhibited by amoeba.

The amoeboid movement is by no means confined to protozoa. Amongst the protozoa it is exhibited by foraminifera, radiolaria, heliozoa and myxomycetes. It is also exhibited by *amoebocytes* of sponges and the young stages of sponge. Sperms of many animals and zoospores of certain plants also exhibit such movements. Amongst higher animals such a movement is exhibited by the fibroblasts, leucocytes (white blood corpuscles), phagocytes and epithelial cells in tissue-cultures. Various theories have been propounded to explain the actual physiology of this movement but the most widely accepted is the **'sol-gel'** theory or the **change of viscosity theory** of Mast which has already been explained (vide the preceding chapter).

7

Structure of Euglena

Give the structure of *Euglena* in detail. Give reasons for including it in the Animalia. (For diagram see p. 34).

The plant-like characters of *Euglena* are: (i) presence of true chlorophyll and *photosynthesis* (ii) absence of holozoic nutrition and (iii) presence of plant-like mode of nutrition: the *holophytic* mode; it also nourishes by saprophytic mode; nutrition in *Euglena* is therefore **mixotrophic.** The animal like characters of *Euglena* are (i) *active automatic movements* due to the lashing movements of the flagellum, presence of *myonemes*, distinct contractile fibrils in the axial filament of the flagellum; the sheath of the flagellum of *Euglena* is supposed to be muscular in nature: the myonemes can be taken to be fore-runners of the muscular system of higher animals. Muscular system is characteristic of animals. *Euglena* also exhibits *euglenoid movements* or *metaboly* in which the animal exhibits worm like contractions and expansions of the body. *Euglena* leads a very active and *sentient life* (sentiment-conscious, capable of sensation, responsive to stimuli) characteristic of animals. The behaviour of *Euglena* is quite like that of an animal. Despite possession of certain plant like characters, *Euglena* is therefore considered as an animal.

Euglena is a solitary, free living fresh water protozoon. The body is spindle shaped with a blunt anterior and a tapering posterior end. The anterior end bears a flagellum. At the anterior end there is an opening cytostome, leading to a gullet and reservoir which together constitute a *cytopharynx* from the base of which the long vibratile flagellum arises by two roots, each connected to a basal granule or blepharoplast. The flagellum is extremely slender, has a central axial filament or *axoneme* formed of myonemes round which is a fibrillar protoplasmic sheath. The flagellum is locomotory in function. Euglena's body is invested by a shape giving, thin, firm, resistant and elastic cuticular covering membrane—the *pellicle* which shows oblique striations disposed parallely or spirally. In the body, outer *ectoplasm* and inner granular *endoplasm* are distinct. The cytoplasm contains imbedded in it the *nucleus, eyespot, contractile vacuole, chromatophores* and certain other inclusions.

Stigma, the red spot lying on the side of cytopharynx represents a *light perceiving organelle.* Its red pigment is *haematochrome.* The anterior end of Euglena is more sensitive to light. There is a single large *contractile vocuole* which pulsates rythmically, discharges fluid into the reservoir and *regulates* the water-content of the body i.e. is osmoregulatory in function. Around the contractile vacuoles are found 'accessory' or 'formative vacuoles'. Conspicuous *chromatophores* containing *true chlorophyll* are found which bring about true photosynthesis. In the centre of chromatophores is a thin and non-pigmented '*pyrenophore*' round which biconvex *pyrenoid bodies*—reserves of protein are found. Surrounding each pyrenoid is found a *paramylum* (or paramylon) *sheath.* Paramylum is a polysaccharide and is a kind of starch which does not give the iodine test. Certain spindle-shaped or rounded subpellicular mucous secreting bodies may also be found in the endoplasm which probably help in encystment during unfavourable conditions. **Nucleus** is large and spherical and lies in the posterior half of the body. It has a *nucleolus* or endsome.

Kept in the dark for extended periods, *Euglena* loses green colour of chromatophores temporarily; such an animal which has been rendered pale in darkness is known as *etiolated.*

8

Mode of Nutrition in Amoeba, Euglena and Paramecium Compared

Amoeba	Euglena	Paramecium
1. Solid food is ingested i.e. nutrition is *holozoic*.	1. Holozoic nutrition is not found. Instead the nutrition is dual : i.e. *mixophytic* i.e. both (i) *holophytic* or *autotrophic* (assimilating carbon by photosynthesis) and (ii) *saprophytic* absorbing dissolved nutrition through the general body surface.	1. The nutrition is *holozoic*.
2. No photosynthesis occurs.	2. True photosynthesis occurs in which food is synthesised out of CO_2, solar energy and water by chlorophyll.	2. Photosynthesis does not occur.
3. The *pseudopodia* are specialised organelles for ingestion as well as locomotion.	3. No specialised organellae of feeding are found. Flagellum and cytopharynx are present but their function as feeding organellae is only *probable*, for the holozoic mode of nutrition has not been observed.	3. The ingestatory apparatus is highly complicated and is equipped with specialised ciliature. The oral groove, the vestibule, the cytostome, the cytopharynx and the oesophageal tube are all differentiated and specialised for ingestion; the cilia create a feeding current.
4. The food consists of small solid particles : minute protozoa, algae, rotifers, bacteria and diatoms etc.	4. The food does not contain solid particles. Dissolved food is absorbed through the surface.	4. The food consists of small solid particles, the food largely consists of bacteria, yeast cells and other micro-organisms.
5. The region of food-intake is not fixed ; it may occur at any point on surface.	5. The region of food-intake is not fixed.	5. The food is taken only through the cytostome and the cytopharynx ; the region of food-intake is thus fixed.
6. Food is ingested by *import*, *circumfluence*, *circumvallation* or *invagination*; in the second and third of these devices, *pseudopodia* or protoplasmic processes form a food-cup.	6. Solid food is not ingested and these processes are not found. *Pseudopodia* are never formed.	6. None of these devices are founded during the ingestion. Instead, the ciliary tracts of the oral groove drive a current of water loaded with food particles. The ciliary tracts drive the food particles down to the cytostome wherefrom they are taken into the cytopharynx, oesophagus and lastly in the oesophageal sac which has a fine elastic membrane. This sac having accumulated food particles is released into the endoplasm as a *food vacuole*.
7. Food vacuoles are always formed but these do not undergo *cyclosis*.	7. Food vacuoles are not formed and hence no question of cyclosis.	7. Food vacuoles are always formed and these undergo *cyclosis*.
8. The food vacuoles move inside the endoplasm with cytoplasmic streaming during which digestion and absorption occur. Uniform	8. Question does not arise as there are no food vacuoles.	8. The food vacuoles move in cytoplasm in a definite course called *cyclosis* which ensures uniform distribution of food.

Amoeba	Euglena	Paramecium
distribution of nutrition is ensured by movements of food vacuoles. The course of movement of food vacuole is not at all fixed.		
9. The food vacuole is first acidic and then it becomes alkaline.	9. No food vacuole is found.	9. The food vocuole is first acidic and then it becomes alkaline.
10. It can digest proteins (by peptidase and proteinase), fats and starch.	10. Synthesises food by CO_2, water and sunlight. Other absorbed organic matter is also utilised as food.	10. Proteins, carbohydrates, fats and oils can be digested and enzymes for digestion of these are present.
11. Aminoacids may be found in the form of crystalline inclusions. Other reserves may also be found.	11. Reserve food is stored in the form of *paramylum* or *paramylon*—a polysaccharide closely allied to starch but which does not turn blue when treated with iodine differing in this respect from starch. *Pyrenoids* probably represent reserve proteins.	11. Reserve food consists of fat globules, lipoid granules, carbohydrates, glycogen, proteinaceous chromidia and volutin granules.
12. Egestion occurs at any point on the body surface by a temporary rupture or pore in the plasmalemma.	12. Egestion does not occur except expulsion of water by the pulsating contractile vacuole. Dissolved excretory substances are passed out through the general body surface.	12. A definite and fixed **cell-anus** or **cytopyge** is found behind the oral groove on the oral side for egestion. Waste residue is passed out through the cytopyge.

Note—The diagrams of food intake by Amoeba given in that chapter and the diagram showing cyclosis of food vacuole in Paramecium may be given in this chapter.

9

Life-Cycle of Trypanosoma Gambiense

The trypanosomes belong to the order **Protomonadina,** class **Mastigophora** under the phylum **Protozoa.**

The *Trypanosoma gambiense* causes *sleeping sickness* in man. The patient at first develops fever ; his lymph glands become enlarged and anaemia is caused. The patient falls into a heavy unnatural slumber, he becomes unconscious due to invasion of his cerebrospinal fluid by the *Trypanosoma.* The 'heavy slumber' or unconsciousness ultimately leads to death. The **sleeping-sickness** is common in Central Africa.

The African antelopes are immune to *Trypanosoma gambiense* and hence act as reservoirs of the flagellate. It does not cause disease or discomfort to this mammal (antelope) in whose blood the flagellates (*Trypanosomes*) live. The insect tsetse fly *Glossina palpalis* bites the antelope and along with the blood sucked, the trypanosomes are also sucked in the digestive tract of the fly through its proboscis. Inside the intestinal tract of the fly they undergo a *cycle of development* passing through *Leishmania* and *crithidial* forms and finally in about 20 to 30 days, form long slender trypanosomal forms ; this mode of transmission by the secondary host is known as the *cyclic transmission.* Mechanical transmission may also occur.

From the gut, the trypanosomes reach the salivary glands where they are ready for re-infection : when the tsetse-fly bites a man, the saliva comes out and along with it the trypanosomal forms are inoculated into the blood. In man they undergo incubation (multiplication) and ultimately invade the cerebrospinal fluid causing sleeping sickness and death.

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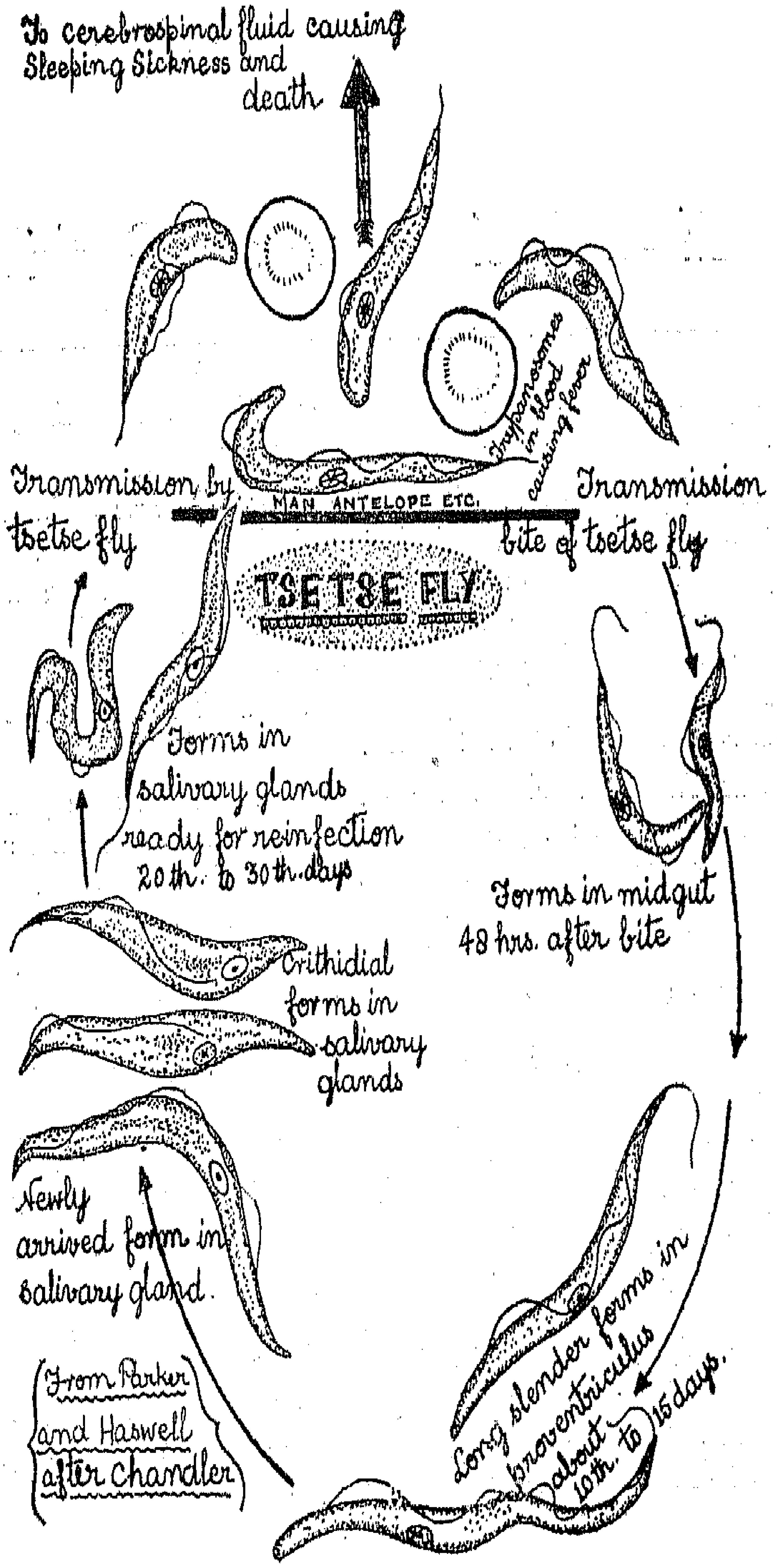

To cerebrospinal fluid causing Sleeping Sickness and death
Trypanosomes in blood causing fever
Transmission by tsetse fly
MAN ANTELOPE ETC.
Transmission bite of tsetse fly
TSETSE FLY
Forms in salivary glands ready for reinfection 20th. to 30th. days
Forms in midgut 48 hrs. after bite
Crithidial forms in salivary glands
Newly arrived form in salivary gland.
Long slender forms in proventriculus about 10th. to 15 days.
(From Parker and Haswell after Chandler)

Fig. 55. Life-cycle of Trypanosoma gambiense.

10

Entamoeba Histolytica

Entamoeba histolytica lives in the human intestine and is the only pathogenic amoeba causing in man, **amoebic dysentery** or **blood dysentery**. Sixty per cent of Indians harbour *Entamoeba histolytica* either in the vegetative or the infective phase. A large number of men apparently free from the amoebic dysentery are in fact really not free from it; they have become used to the disease permanently. Such permanently infected persons are known as '**carriers**' and are dangerous, for they spread out infec-

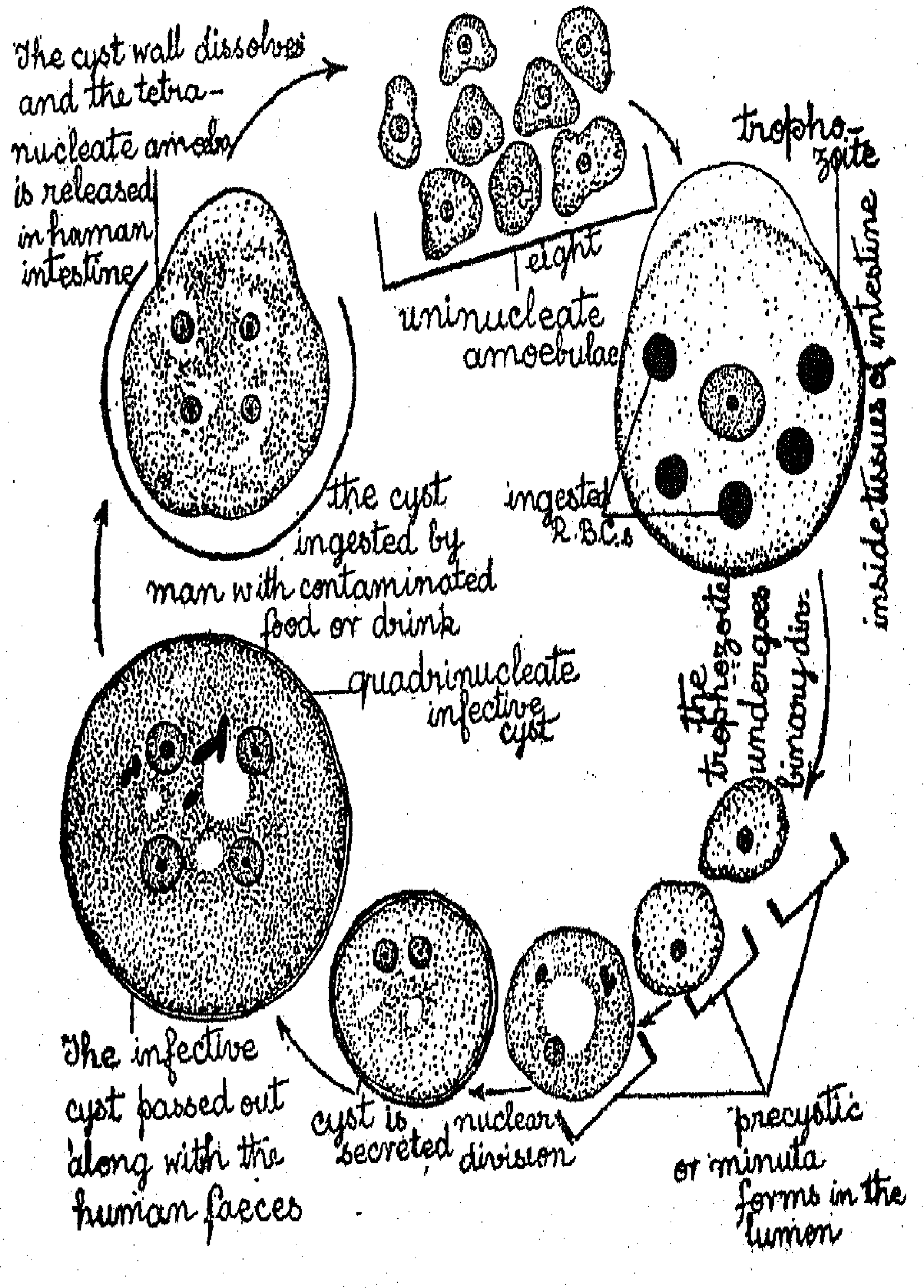

The cyst wall dissolves and the tetra-nucleate amoeba is released in human intestine
eight uninucleate amoebulae
tropho-zoite
inside tissues of intestine
ingested R.B.C.s
the cyst ingested by man with contaminated food or drink
quadrinucleate infective cyst
The trophozoite undergoes binary div.
The infective cyst passed out along with the human faeces
cyst is secreted
nuclear division
precystic or minuta forms in the lumen

Fig. 56 Life-cycle of Entamoeba histolytica.

tion by constantly passing out the spherical cysts which are swallowed by other men with contaminated food or drink. The cyst wall is dissolved, releasing small uninucleate amoebae which by an enzyme 'histolysin' which they secrete, rupture first the superficial mucus membrane and then the deep submucosa of the intestine. The **Histolysin** also removes the walls of blood capillaries as a result of which a huge loss of blood occurs which goes out with man's excreta. The germ (*trophozoite*) feeds upon the living cells, tissues and red blood corpuscles. The preliminary symptoms of the disease are chronic diarrhoea, constipation, headache, nervousness and restlessness. In later stages, the organisms eat into the tissues of the intestinal wall and form ulcers (open sores discharging pus) in bowels causing acute dysentery. When the capillaries of ulcers rupture, acute haemorrhage occurs. The stools contain large quantities of mucus and blood along with cysts. The patient also develops fever. The accompanying diagram explains in full the various stages of the life-cycle which is entirely asexual. There is no secondary host. The life-cycle consists of a **vegetative phase** and an **infective phase** (precystic and cystic stages). Hygienic precautions, and proper sanitary disposal of faecal matter are preventive measures. Persons with dirty finger nails and dirty habits, flies and other insects should always be avoided. **Emetin** and **Yatren** are drugs for treatment.

11

Life-Cycle of Monocystis

Give an account of the life-history of Monocystis.
(Allahabad, 1954)

Monocystis belongs to the order **Gregarinida** under the class Sporozoa (Phylum Protozoa). *Monocystis* is exclusively parasitic (in the seminal vesicle of earthworm), lacks specialised locomotory organellae in the adult condition, lacks a contractile vacuole, mouth opening and excretory pores; *resistant spores* are formed in plenty immediately after the sexual processes (hence placed in **Sporozoa**). The trophozoite is free and motile (**Gregarinida**).

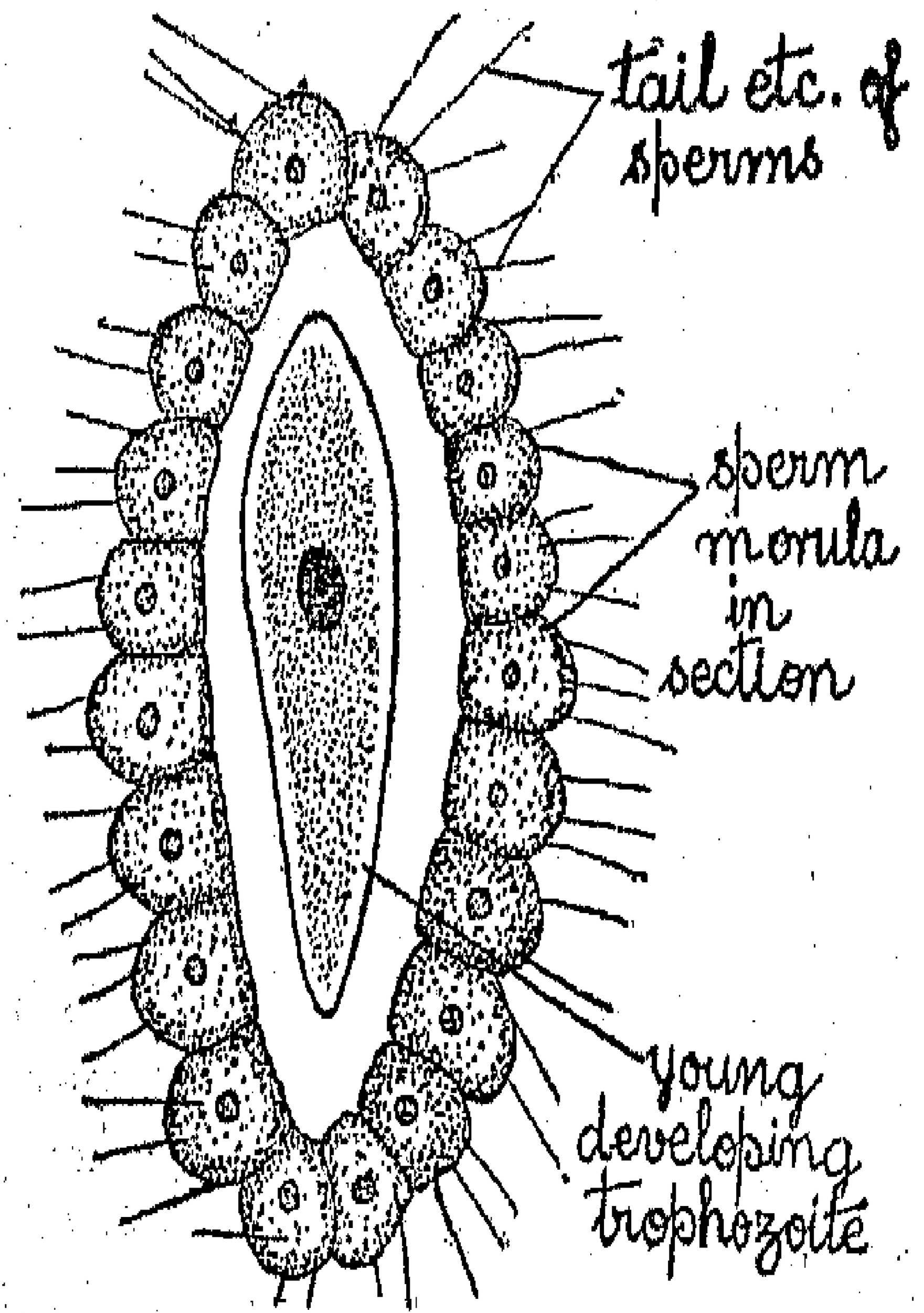


Fig. 57. Sperm morula showing a developing trophozoite.

The spindle shaped **trophozoite** representing the *vegetative phase* is found in the cavity of the seminal vesicles of earthworm. The trophozoite wriggles about and exhibits *gregarine movements* caused by waves of contraction and expansion passing along the myonemes which form the inner layer of the cortical region or ectoplasm. The trophozoite feeds saprozoically on sperm morula cells and respires and excretes by diffusion through body surface. It contains a single large nucleus.

After having stored sufficient reserves of food in the form of a carbohydrate **paraglycogen** and after attaining maximum size, the trophozoites round off and associate by their sides in pairs in **syzygy.** Now known as **gametocytes** or gamonts, they become

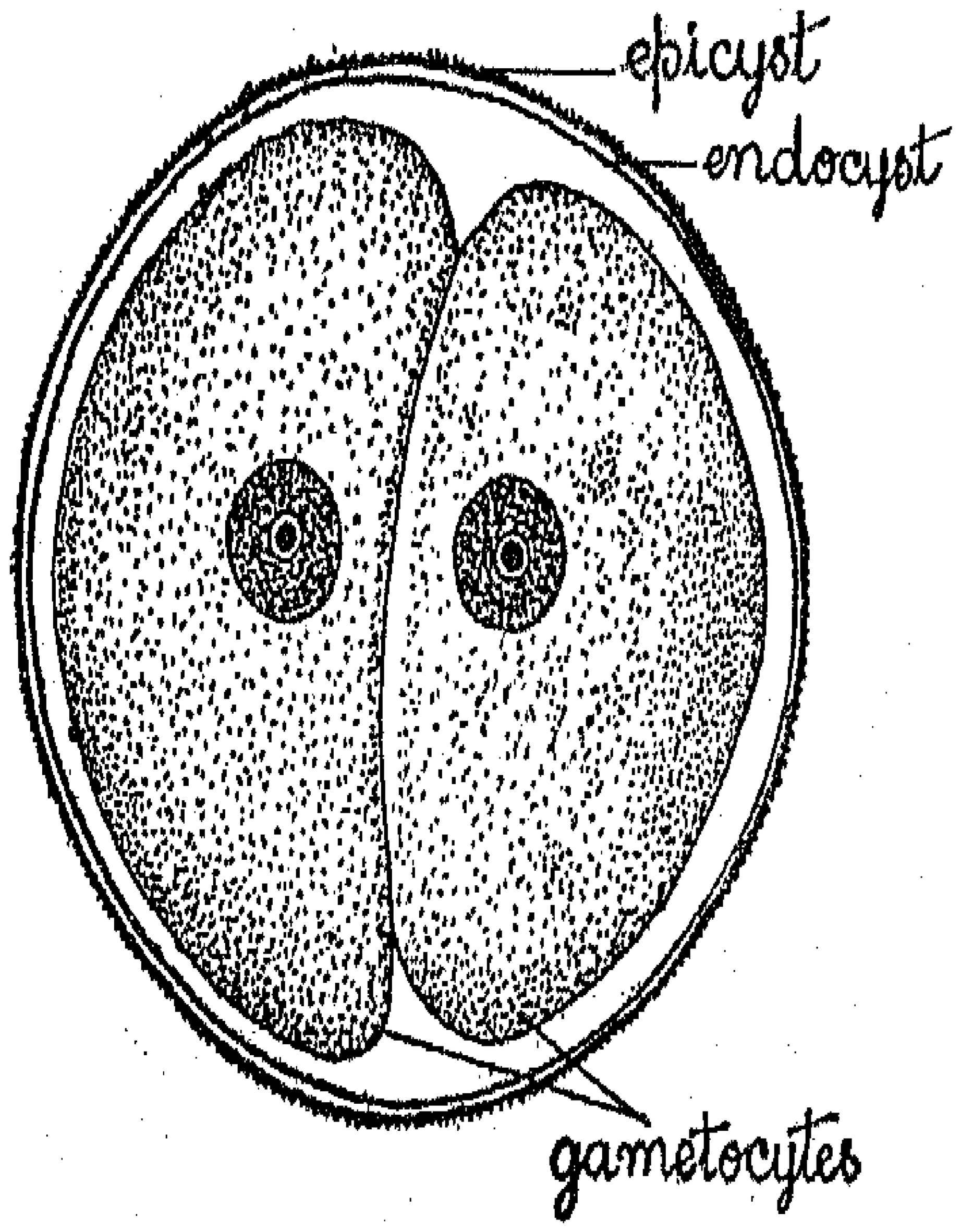


Fig. 58. The gametocytes inside the cysts, the epicyst and endocyst together form the gametocyst.

enclosed in pairs in double walled cyst—the *gametocyst*. This side to side association in pairs of the gametocytes is referred to as **syzygy**. Strictly speaking, the term **syzygy** implies attachment of individuals for reproduction end to end, but the term is used in case of *Monocystis* rather loosely. The nucleus of each gametocyte undergoes repeated mitotic divisions; the last division is a reduction division. As a result a large but equal number of haploid nuclei are formed in each gametocyte. These nuclei become arranged towards the periphery and taking a fragment of cytoplasm, each becomes a *gamete*. The intervening wall between the two gametocytes disintegrates; fusion in pairs occurs between the gametes coming from different gametocytes. The gametes which are all similar are called isogametes. By the fusion of isogametes, diploid **zygotes** are formed. It undergoes a period of rest, secretes a stiff chitinoid covering, the *sporocyst* around it and is now called **sporoblast**; its nucleus undergoes three mitotic divisions forming eight sickle shaped *sporozoites*. The sporocyst is boat like in shape and along with the sporozoites, is known as *spore* or **pseudonavicella**.

The gametocyst disintegrates releasing the spores in the cavity of the seminal vesicles. No further development occurs after this stage unless and until the spore is transferred to a fresh earthworm. If the infected earthworm dies, the spores liberated in the soil are ingested by other earthworms. Or, the earthworm with spores in its seminal vesicle is ingested by a bird. The spores are passed out along with faeces of the bird. Reaching the soil, these spores are ingested by fresh earthworms during their surface feeding. In the third method of dispersal, the spores are passed out along with sperms during copulation and are thus transferred to a fresh earthworm.

The sporocyst is dissolved in gut of the earthworm, liberated sporozoites penetrate the gut wall and through the ciliated funnels

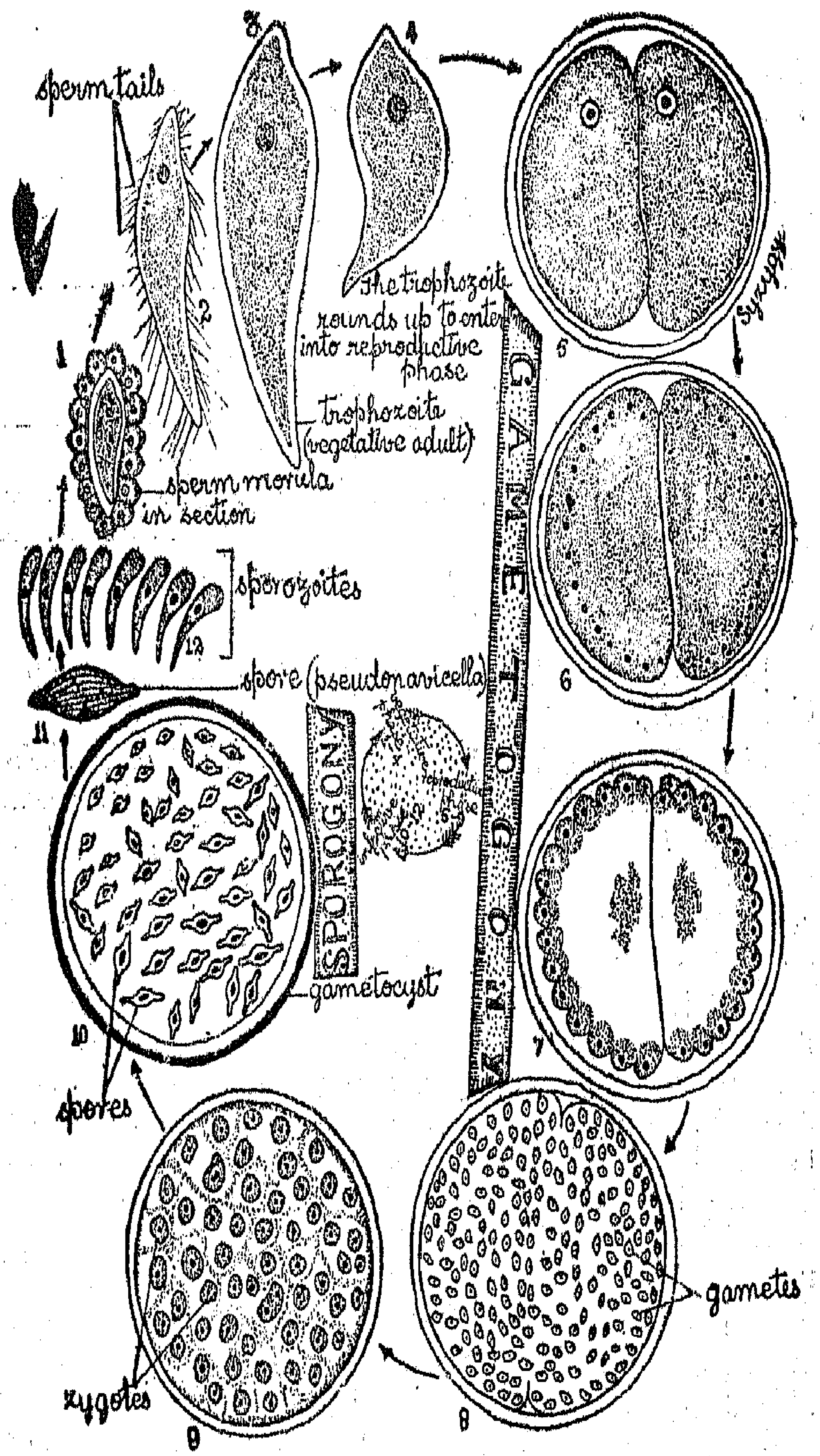


Fig. 59. Life cycle of Monocystis.

reach the seminal vesicles where inside the sperm morulae, the sporozoites grow into trophozoites.

Monocystis is not pathogenic. Its life-cycle is a single host life-cycle. It is exclusively *parasitic* and this mode of life has resulted in retrogression and suppression clearly manifest in the loss of mouth, cytopharynx, contractile vacuole, eye spot or sense organellae, and locomotor organellae. The reproductive activities are exaggerated, the **gametogony** and **sporogony** are prominent while the **schizogony is remarkably absent.**

12

The Life-History of Plasmodium, the Malaria Parasite of Man; Its Comparison with the Life-Cycle of Monocystis

1. **Give an account of the life-history of the malarial parasite in man.** (L. U. B. Sc, 1959)

2. **Give an account of the life-history of Monocystis and compare it with that of Plasmodium.** (L. U. B. Sc, 1955)

[Note—For the life-cycle of Monocystis, please see the preceding chapter].

Plasmodium causes malaria in man. It is a protozoon belonging to the class **Sporozoa**, order **Haemosporidia**; its vegetative adults or *trophozoites* live in the human erythrocytes (red blood corpuscles) and eat them away. The patient suffers from fever, grows very weak and may even die if not adequately treated. The fever thus caused is known as **malaria**.

Man is the **main host** (or primary host) and harbours the adult stage, the trophozoite of *Plasmodium* in his blood. **Schizogony** (in which the trophozoite divides asexually and produces numerous units called merozoites) also occurs in man's blood. Sexual cycle of *Plasmodium* occurs in the female mosquito *Anopheles* in which the sporogony also occurs. The **female** *Anopheles* is therefore known as the **intermediate**, **secondary** or the vector host.

The **paroxysm** and **ague** (a burning fever with hot and cold fits) occur in man due to toxic substances released into the blood when the infected erythrocytes break up and disintegrate.

The naked *sporozoites* of Plasmodium inoculated into the blood of man by the bite of the female Anopheline mosquito (which had them in its salivary glands and which reach the blood of man along with the mosquito's saliva extruded to administer the anticoagulant secretion prior to its blood meal) *first of all infect the liver of man.* Immediately after the mosquito's bite, no sporozoites are found in the blood; they seem to disappear but actually they straightaway migrate to liver with the blood stream. No red-blood corpuscles are attacked *immediately* after infection. Penetrating the parenchymatous cells of liver, the sporozoites feed and grow into **trophozoites** which after eight to nine days come to be known as *schizonts* which are ready to divide asexually. The

nucleus of schizont divides into is as many as one thousand nuclei all of which along with some cytoplasm form minute *uninucleate merozoites* also called micromerozoites due to their very small size.

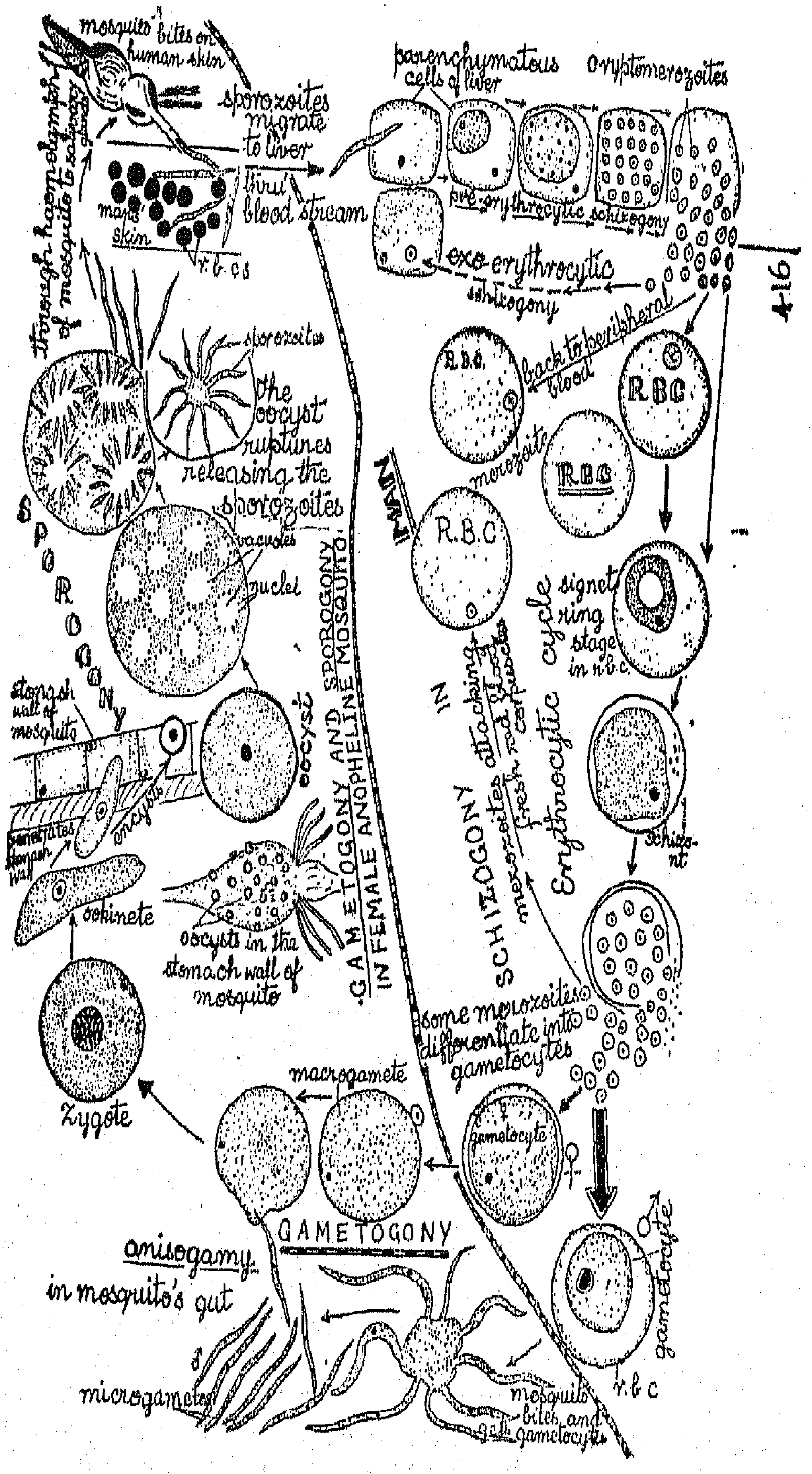

mosquito bites on human skin
sporozoites migrate to liver
thru' blood stream
man's skin
r.b.cs
through haemolymph of mosquito to salivary glands
parenchymatous cells of liver
cryptomerozoites
pre-erythrocytic schizogony
exo-erythrocytic schizogony
back to peripheral blood
416
sporozoites
the oocyst ruptures releasing the sporozoites
vacuoles
nuclei
SPOROGONY
R.B.C.
RBC
merozoite
RBC
R.B.C
MAN
signet ring stage in r.b.c.
GAMETOGONY AND SPOROGONY IN FEMALE ANOPHELINE MOSQUITO
IN
SCHIZOGONY
merozoites attacking fresh red blood corpuscles
Erythrocytic cycle
stomach wall of mosquito
oocyst
oocyst
penetrates stomach wall
ookinete
oocysts in the stomach wall of mosquito
Schizont
some merozoites differentiate into gametocytes
macrogamete
Zygote
gametocyte
♀
GAMETOGONY
anisogamy in mosquito's gut
♂
microgametes
mosquito bites and gets gametocytes
♂ gametocyte
r.b.c

Fig. 60. Life-history of Plasmodium.

The micromerozoites produced in liver are called *cryptomerozoites* (crypto=hidden) because they are not detected in blood, immediately after the infective bite. The process in which the trophozoite becomes a schizont and multiplies asexually (by multiple fission) to form a huge number of micromerozoites is known as **schizogony.** The schizogony in the liver is known as the **pre-erythrocytic schizogony** because it occurs before a similar schizogony in blood. The pre-erythrocytic trophozoite (the one found in liver) is called a cryptozoite.

The infected liver cells rupture and the cryptomerozoites released enter the blood stream, attack the red blood corpuscles and initiate the **erythrocytic cycle**. [The period elapsing between the bite of mosquito and the first attack of merozoites on the red blood corpuscles is known as the **incubation period** which is also the time period taken by the first pre-erythrocytic schizogonic cycle to complete; this period varies between 8 to 15 days and is fixed for every species of Plasmodium. *The incubation period is also therefore the period between mosquito's biting and man's fevering.*]

Some cryptomerozoites may infect fresh liver cells and repeat the schizogonic cycle. These schizogonic cycles inside the liver are known as **exo-erythrocytic cycles** and these keep producing merozoites which are released into the blood stream from time to time. The cryptomerozoites of the exo-erythrocytic cycles remain inside liver, spleen and bone marrow in the reticulo-endothelial cells. The pre-erythrocytic and exo-erythrocytic cycles explain the following facts of malaria: (i) *the incubation period,* (ii) *the latent period* (the infected man gets no fever) and (iii) *the relapse period* which may be several months or even years. The patient is apparently cured by medicines which kill the parasites of blood but their establishment remains in the liver and reticulo-endothelial cells which may release the merozoites into blood stream after long periods. Invading the erythrocyte, the cryptomerozoite grows into a trophozoite and passing through a *signet-ring stage* becomes the **schizont** which produces a large number of merozoites (6 to 24) by schizogony. The liberated merozoites attack fresh erythrocytes repeating the schizogony.

After repeated schizogonic cycles some of the resulting merozoites do not pass through the signet-ring stage and instead form small **microgametocytes** with a large nucleus and clear cytoplasm and large macrogametocytes with small nucleus and sufficient reserve of food in its cyptoplasm. The gametocytes do not develop in man and must be ingested by the female Anopheline mosquito in whose stomach they undergo *gametogenesis.* Each microgametocyte by a process of flagellation produces two to eight haploid motile **microgametes** or **male gametes**; each macrogamete undergoes maturation and forms a single haploid **macrogamete** or female **gamete** which develops a cone of reception. Anisogamy involving complete fusion of the micro- and macrogamete results in the formation of a diploid **zygote** which soon resumes activity and forms a motile vermicule **ookinete** which bores into the stomach wall and puts on a thin non-resistant cyst; now it is known as **oocyst** and comes to lie between the epithelial and subepithelial tissues of the stomach wall. A single mosquito may have hundreds of oocysts on its stomach wall. The oocyst soon grows into a sporont.

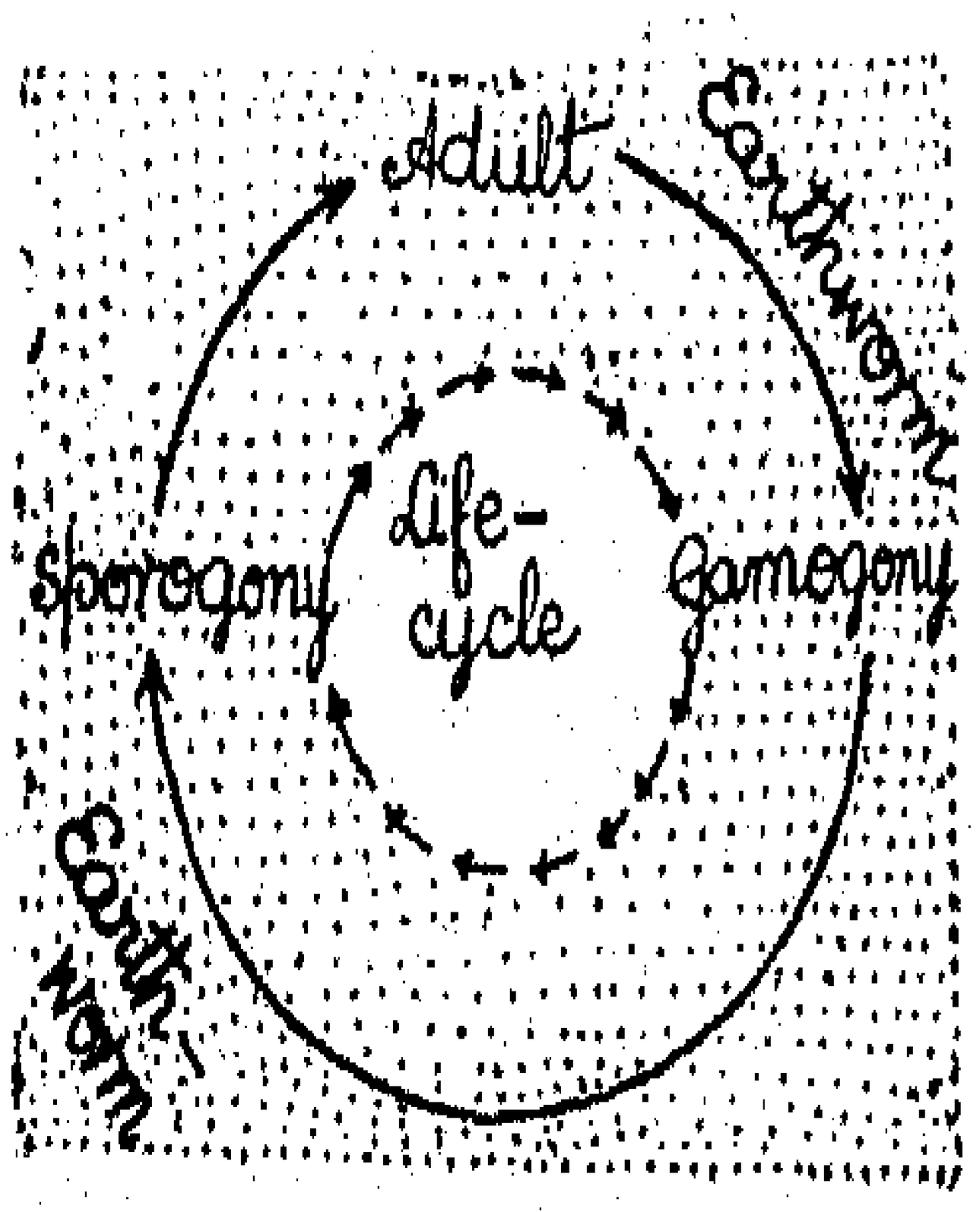
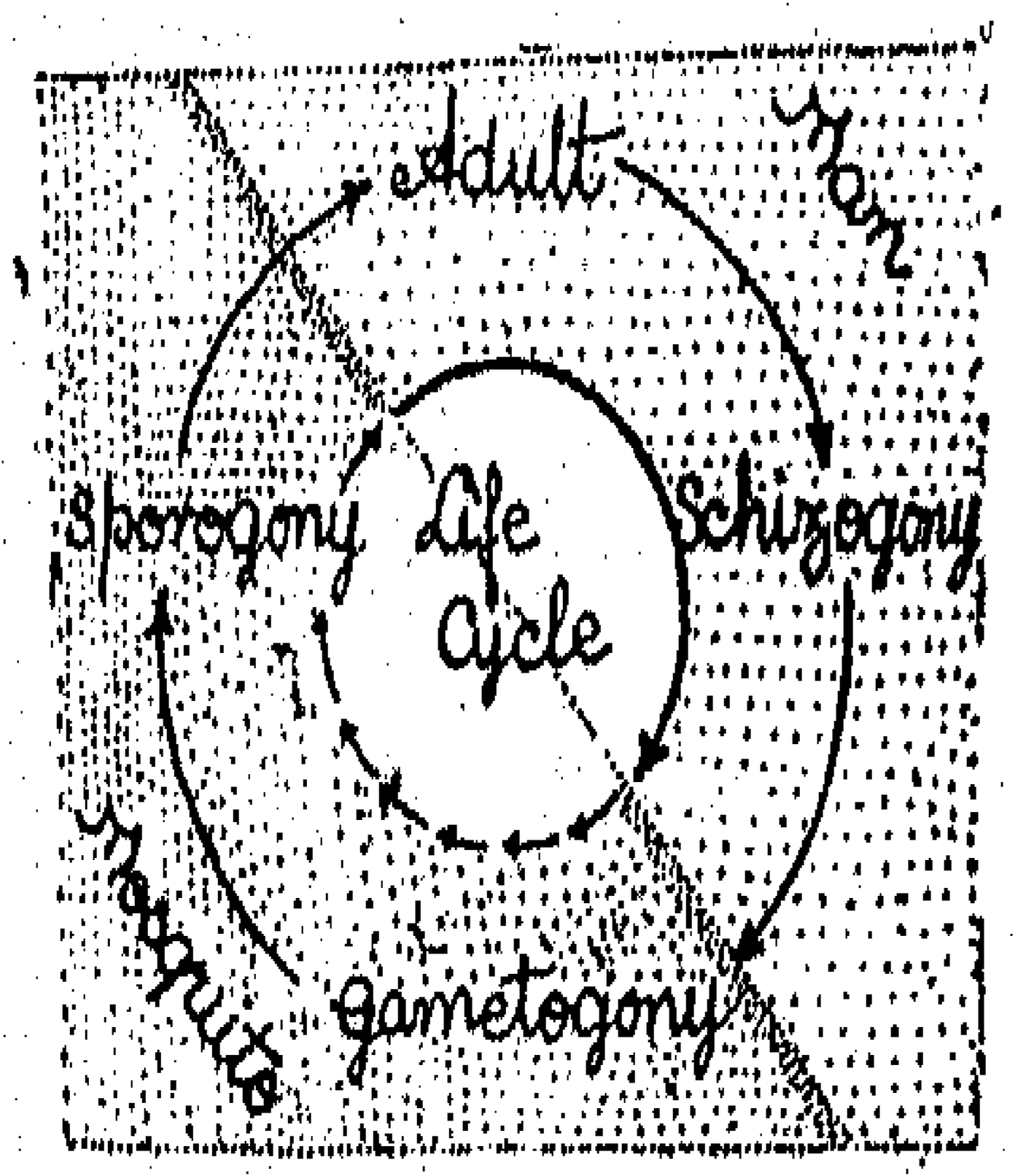
The nucleus inside the oocyst multiplies to form a large number of nuclei which may be as many as ten thousand. A large number of vacuoles appear in the cytoplasm; the nuclei become arranged around the vacuoles; the nuclei along with a speck of cytoplasm project into the vacuole as elongated fusiform structures known as the sporozoites. The cyst is now called a sporocyst; it bursts open and releases thousands of minute sporozoites into the haemocoelomic fluid of the mosquito. Through the haemolymph, the sporozoites reach the *salivary glands* of the mosquito *where* they become established in a ready stage for infecting a fresh human host through the mosquito bite. The inoculated sporozoites, reaching the human blood first of all reach the liver, initiate a *pre-erythrocytic cycle* and produce cryptomerozoites which attack the red blood corpuscles again.

Thus the life-cycle involving pre-erythrocytic schizogony, and exo-erythrocytic schizogony, gametogony and sporogony is now completed. A **distinct alternation of asexual and sexual generations** occurs, the former occurring in man and the latter in the female Anopheline mosquito. Schizogony occurs in man, gametogony and sporogony occur in the female Anopheles. Gametogony involves the sexual process. The male Anopheles does not take blood meals and hence does not cause malaria.

Plasmodium vivax completes schizogony in 48 hours and causes **'Benign tertian'** the fever which attacks every third day, the fever is not serious. *P. malariae* completes the schizogony in 72 hours and causes **Quartan fever** which attacks every fourth day; the fever is not serious. *P. falciparum* causes irregular attacks of fever, schizogonic cycle takes no definite period, causes serious, rather fatal **Malignant tertian fever**; this species causes maximum death and is the most dangerous species. *P. ovale* also completes schizogony in 48 hours and causes **Benign tertian fever.**

Monocystis	*Plasmodium*
1. The trophozoite is free and motile (characteristic of the order Gregarinida) and has more or less a definite shape. The trophozoite is uninucleate.	1. The trophozoite is amoeboid and lives intracellularly in the red blood corpuscles (erythrocytes). The trophozoite is uninucleate.
2. The trophozoite lives in the seminal vesicles of earthworm.	2. The trophozoite lives in the erythrocytes of the vertebrate host.

Monocystis	*Plasmodium*
3. The entire life-cycle is a single host life-cycle.	3. Two different hosts, man and female Anopheles are needed for completion of the life-cycle.
4. The adult trophozoite is *coelozoic* (the parasite which lives in a cavity is known as *coelozoic*).	4. The adult trophozoite is intracellular or *cytozoic* (the parasite which lives inside a cell is called *cytozoic*).
5. The trophozoite does not cause any disease to its host (i.e. earthworm).	5. The trophozoite causes malaria in man, the main host, but no disease to the mosquito.
6. The trophozoite has *myonemes* or contractile fibrils in the inner layer of its cortex (ectoplasm).	6. The trophozoite lacks myonemes.
7. Due to myonemes, the trophozoite exhibits gregarine movements.	7. The trophozoite does not exhibit such movements.
8. No signet-ring stage is found.	8. A signet-ring stage is found in the trophozoite developing into a schizont.
9. The trophozoite feeds upon the sperm-morula cells saprozoically.	9. The trophozoite feeds saprozoically upon the red blood corpuscles.
10. The trophozoite has no pigments.	10. The trophozoite has *haemozoin* (melanin) pigment.
11. The adult trophozoite does not reproduce asexually.	11. The trophozoite grows into a *schizont* which multiplies by asexual multiple fission (schizogony).
12. Alternation of generations does not occur.	12. The asexual generation in man (or other vertebrate) alternates with sexual generation in mosquito. Thus there is distinct alternation of generations along with alternation of hosts.
13. No incubation period is found.	13. Incubation period is found in which the parasite undergoes schizogony in liver.
14. Syzygy is found.	14. Syzygy is not found.
15. The fully grown trophozoites form the gametocytes.	15. The merozoites (and not the trophozoites) form the gametocytes.
16. *Gamogony* (multiple fission leading to formation of gametes) occurs in the same host in which the trophozoite lives.	16. Gamogony occurs in the secondary or the intermediate host,—the mosquito.
17. The gametocytes get encysted in pairs prior to gamete formation.	17. The gametocytes do not get encysted.
18. The gametocytes produce equal number of gametes which are *isogamous*.	18. The gametocytes produce anisogamous gametes : the *microgametes* and the *macrogametes* which differ from each other morphologically as well as physiologically. The number of gametes produced by female gametocyte is only one while the male gametocyte produces eight gametes.
19. The number of gametes produced by a single gametocyte is very large. Isogamy prevails.	19. The number of gametes produced is much smaller. Anisogamy occurs.
20. The zygote is nonmotile.	20. The zygote is motile and is known as *ookinete*.
21. The zygote does not bore through the tissues.	21. The ookinete bores through the stomach wall of the mosquito.
22. The zygote develops a *resistant* cyst.	22. The zygote secretes a *non-resistant cyst* and the secretions of stomach wall tissues also contribute in cyst formation.
23. The spore-case is spindle-shaped; one zygote gives rise to *eight* sporozoites. The spore-case is capable of withstanding unfavourable conditions prevailing outside the body of the host in the external world.	23. The *sporocyst* is thin, non-resistant and rounded. The zygote gives rise to thousands of sporozoites. The sporocyst (oocyst) does not have to endure unfavourable conditions of the outside world.
24. The spores are produced in a large number to perpetuate the race despite enormous chances of mortality and waste befalling them in the outside world during dispersal.	24. The spores are produced in a smaller number because they do not have to suffer waste and perish in the outside world.

Monocystis	*Plasmodium*
25. *Transmission* is effected by ingestion of spores by earthworms during surface feeding or during copulation, the spores passing to the fresh earthworm along with the spermatic fluid. Dispersal may also be effected by birds eating the infected earthworms and passing out spores with their faeces.	25. Transmission is effected by the female *Anopheles* mosquito which bites the patient of malaria sucking the gametocytes along with blood and then inoculates the sporozoites into a healthy man's blood during its bite.
26. A part of the life-history occurs outside the body of the host; the specific stage occurring outside is that of spores or *pseudonavicella*.	26. No part of the life-history occurs outside the body of the hosts.
27. No schizogony occurs in the life-history.	27. Schizogony occurs during the pre-erythrocytic, exerythrocytic and erythrocytic phases of the life-history.
28.  Adult Earthworm Sporogony Life-cycle Gamogony Earth-worm Fig. 61	28.  Adult Man Sporogony Life Cycle Schizogony Mosquito Gametogony Fig. 62
29. The life history involves syzygy, gamogony and sporogony.	29. The life-history involves schizogony, gamogony and sporogony. The life history is much more complicated because it involves two hosts, alternation of generations and schizogonic cycles.

It may be added that both *Monocystis* and *Plasmodium* belong to the class **Sporozoa**; *Plasmodium* belongs to the order **Haemosporidia** and *Monocystis* belongs to the order **Gregarinida**. Both these belong to the subclass **Telosporidia** characterised by uninuclear trophozoites and simple spore-cases containing several sporozoites. The class **Sporozoa** to which both belong are characterised by exclusively parasitic members which always multiply by spore-formation. **Haemosporidia** are characterised by an *amoeboid* trophozoite which lives as a parasite in the red blood corpuscles of Vertebrates. **Gregarinida** are characterised by free and motile nature of trophozoites.

13

Structure of Paramecium

Give an account of the structure and physiology of *Paramecium.* **How would you collect paramecia for the purposes of demonstration?** (Allahabad 1949, 1952)

[*Paramecium* is a protozoon belonging to the subphylum **Ciliophora** (characterised by the possession of cilia which are used as locomotor and food catching organellae). *Paramecium* is included in the class **Ciliata** because it is provided with cilia throughout its life. It is further classified under the subclass **Euciliata** as it shows **nuclear dimorphism** (presence of two kinds of nuclei: micro and meganucleus), possesses a feeding apparatus: cytostome and cytopharynx; is free-living and undergoes conjugation. It is placed in the order **Holotricha** as its body has uniform ciliation on the entire body.]

Pond weeds are kept in water in a dish (No. 1) and allowed to stand for a week; the green superficial scum contains amongst other organisms, plenty of *paramecia.* Some wheat grains are boiled in separate water and cooled down; these grains are now kept in fresh rain water (No. 2) or boiled pond water for a day or two. *Paramecia* sorted out from the dish no. 1 are then introduced into the pond water (No. 2) kept in a separate dish.

Paramecium (or slipper-animalcule) occurs in nature in fresh water stagnant ponds where there is decaying vegetation. The body of the animal is light grey, white or pale yellow with a size ranging between 80 and 350 microns. (One micron=1/1000 mm.) The body has fixed anterior and posterior, dorsal and ventral ends and a fixed shape due a thin stiff external elastic cuticular membrane *pellicle.* On the ventral side is found an *oral groove.* Under a high magnification the *pellicle* shows slightly concave hexagonal areas bounded by fine ridges; a cilium projects out from the centre of each such area; each cilium actually arises from a *basal granule* placed immediately beneath the pellicle. The basal granules have in relation to them, a system of longitudinal and transverse fibrils (*Klein's subpellicular system* or the *silver-line system*) which probably co-ordinates the movements of cilia.

The body is covered by cilia of uniform length arranged in more or less parallel rows. At the extreme posterior end is found a conical *caudal tuft* of cilia which consists of cilia, slightly longer than those found all over the body-surface. The cytopharynx bears cilia of varying length on its walls. The cilia exhibit a sort of co-ordination in their movements and are used as locomotor and food-capturing organellae. Structurally cilia possess a central fibrous *axoneme* and a surrounding contractile *protoplasmic sheath.* There is a clear ectoplasm and a granular endoplasm. The ecto-

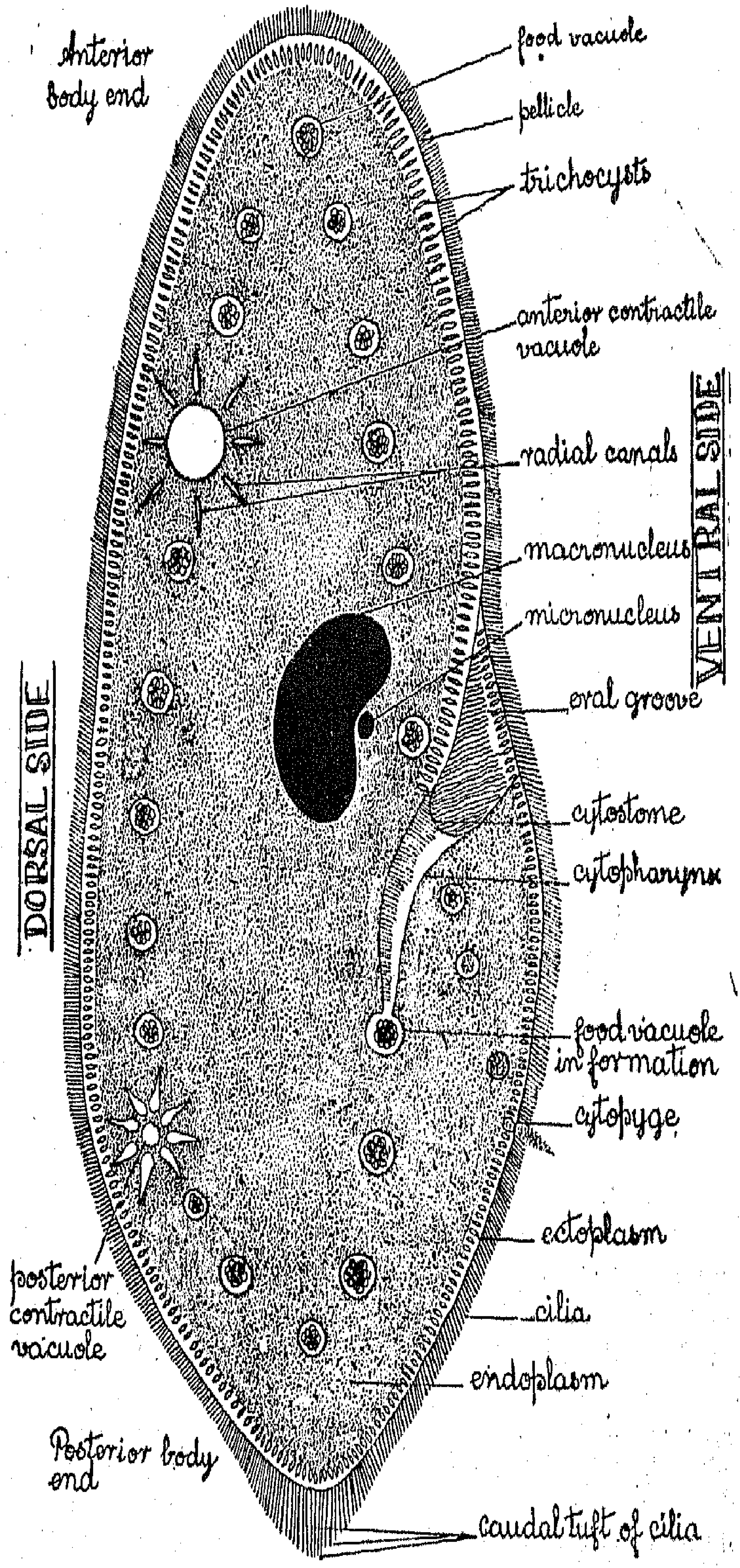


Fig. 63. Paramecium.

plasm contains saclike spindle-shaped *trichocysts* which get discharged on being irritated by an appropriate stimulus tending to inflict injury upon the organism. Each trychocyst hangs vertically beneath the pellicle and opens to the outside by a pellicular pore. During its discharge, the trichocyst throws out a thin and needle like delicate thread six to ten times the length of an ordinary resting trichocyst when it is nearly four microns in length. The action of certain chemicals, desiccation, electric shocks and mechanical pressures or injuries are the stimuli which bring about a discharge of trichocysts. The trychocysts have been considered as organs of defence or offence, although in case of *Paramecium* they are not toxic. In *Paramecium,* they are certainly of use in anchoring its body to solid materials occurring in the environment.

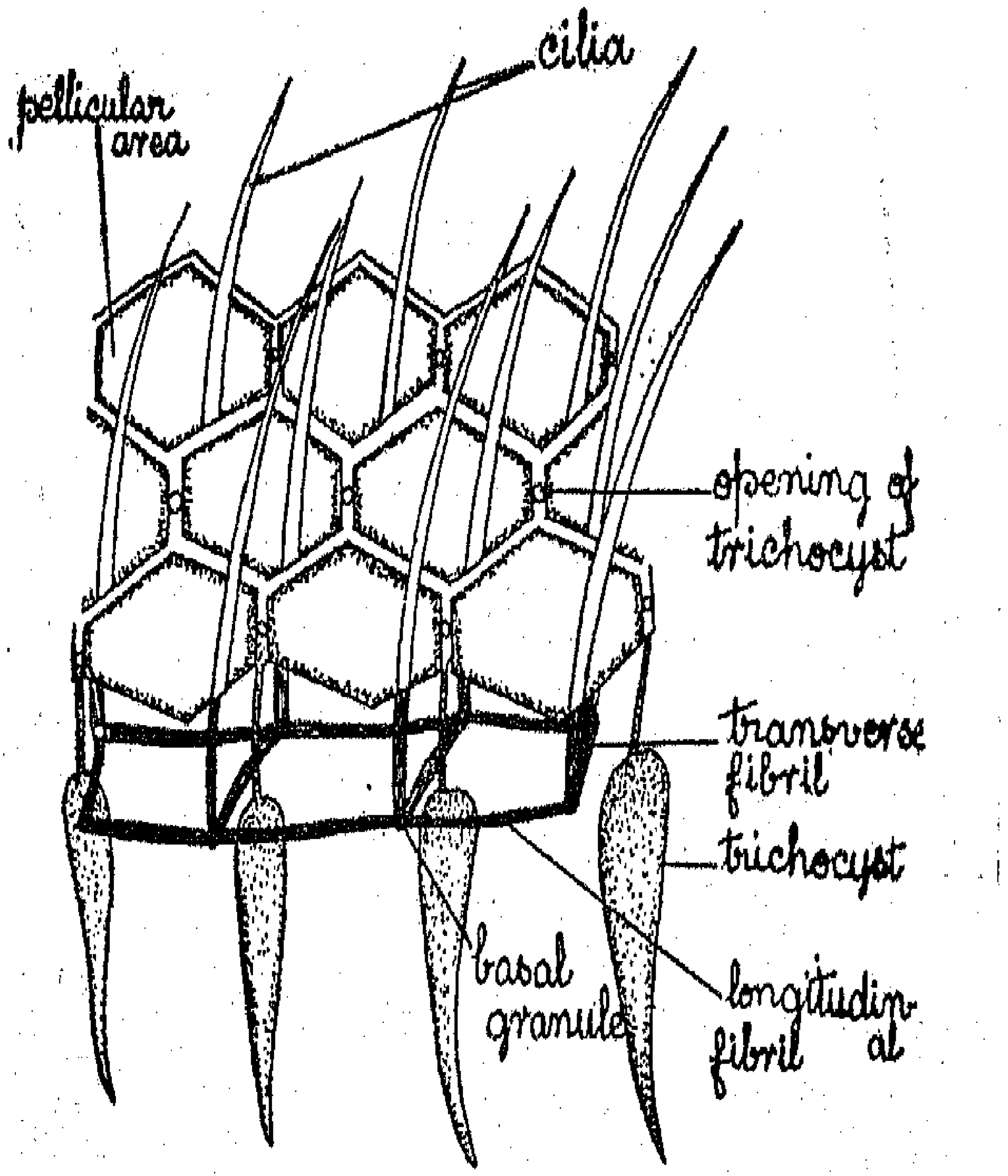


Fig. 64. The pellicle and the silver line system of Paramecium. (Modified after Lund)

The *endoplasm* is more fluid and granular than *ectoplasm.* The endoplasm exhibits characteristic streaming movements (cyclosis) and contains micronucleus, meganucleus, two contractile vacuoles, food vacuoles and reserves of food. The ventral oral groove starting from the anterior end (where it is fairly broad) bends obliquely towards the right side and twisting slightly, tapers and ends in an oval mouth or cytostome. The basal portion of the oral groove is known as *vestibulum* which leads to the cytostome. The cytostome leads to *cytopharynx* which in turn leads to a narrow *oesophagus* ending in the *oesophageal process,* which is a blind pouch and which ends in the endoplasm. A little behind the cytostome on the oral surface lies the **cell-anus** or **cytopyge** observed during defaecation. The dorsal inner surface of cytopharynx has four rows of long cilia ; a heavy band of cilia known as *penniculus* consisting of eight (or more) rows of cilia starting from the left wall of cytopharynx takes a spiral turn so that its posterior end lies on the floor of oesophagus ; a few very long cilia known as *para-oesophageal fibres* arise from the posterior dorsal end of oesophagus and project freely in the endoplasm. About a dozen *post-oesophageal fibres* arise from the right wall of cytopharynx and lie in the endoplasm likewise.

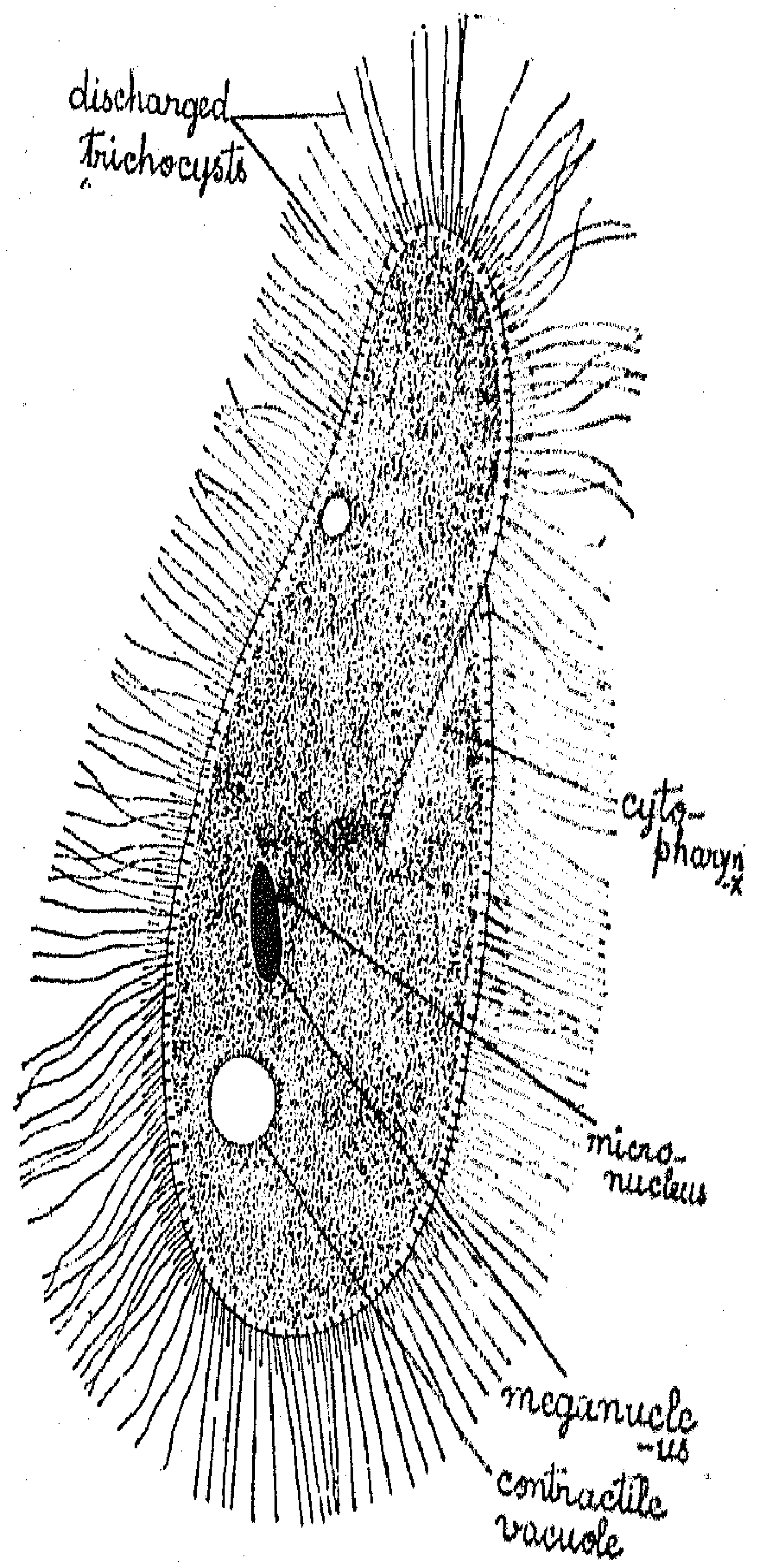


Fig. 65. Paramecium irritated with Methyl green acetic acid. The trichocysts have been discharged by irritation.

There are typically two nuclei in *Paramecium* : one large **macronucleus** or **meganucleus** controlling (vegetative activities) the general metabolism of the body and a small *micronucleus* which is actively concerned in the reproductive processes. Thus there is *nuclear dimorphism in Paramecium*. *Paramecium* has two contractile vacuoles each situated at a short distance from the anterior and posterior body ends. The contractile vacuole of *Paramecium* gets fluid from the feeding canals which form a sort of rosette around it. The two contractile vacuoles form and burst alternately. The food particles ingested through the cytostome are driven down the cytopharynx and oesophagus and are ultimately delivered to the endoplasm in the form of **food vacuoles** which move within the endoplasm in a definite course known as cyclosis. Around the food vacuoles and imbedded in the endoplasm are also found *mitochondria* and certain digestive granules. Probably mitochondria and digestive granules are responsible for secretion of enzymes. *Paramecium bursaria* possesses chlorophyll bearing algae *Zoochlorellae* in symbiotic association with it.

14

Reproduction in Paramecium : Conjugation and its Significance

1. Give a detailed account of the reproductive processes in *Paramecium*. (Alld., 1953, Agra 1947, 1950)

2. Describe the different modes of reproduction found in *Paramecium*. **What is their significance?** [L. U. B. Sc. Prel. 1955]

3. Give a detailed account of conjugation in Paramecium. [L. U. B. Sc. Pass, 1960]

Paramecium reproduces by the following methods :

1. **Asexual**
    - (a) **Transverse binary fission,** the most common method
    - (b) **Endomixis**
    - (c) **Hemixis**
2. **Sexual**
    - (d) **Conjugation**
    - (e) **autogamy and**
    - (f) **cytogamy**

We will describe here only (a) and (d) of the above methods :

1. **Asexual reproduction** by **Transverse binary fission** is the commonest method of multiplication in Paramecium. The animal stops feeding. Both the nuclei enlarge. The micronucleus divides mitotically and the macronucleus divides amitotically. A

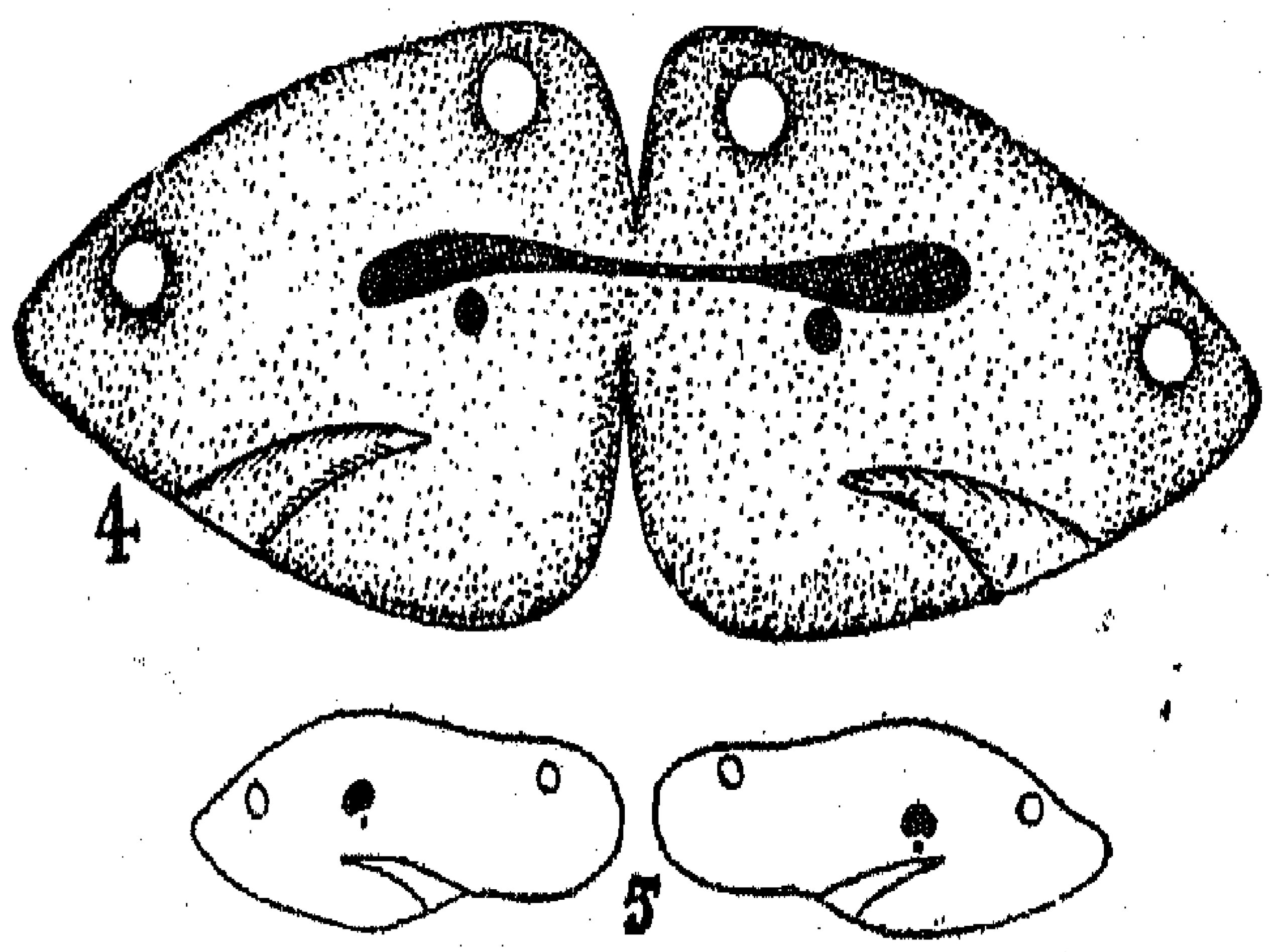


Fig. 66. Final stages in binary fission of Paramecium (Diagrammatic)

deepening constriction develops round the body in the middle region. The cytopharynx produces a *bud* which separates off and comes to lie at the posterior end of the body, the original cytopharynx and other parts of the ingestatory apparatus being retained by the anterior part. This bud develops into a complete cytopharynx for the posterior daughter. The mocronucleus divides amitotically simply by elongation and constriction. Each daughter individual has at first only one contractile vacuole, the anterior one. The constriction in the middle round the cell-body grows and ultimately the two daughter individuals separate. Both of the daughters have all the organellae characteristic of the adult. Feeding is resumed now resulting in growth. The whole process may take about 2 hours or less depending upon the availability of food, temperature and other factors. All individuals derived by successive binary fissions of the same parent are said to form a **clone.**

Continued binary fissions after a long time, produce senile decay manifested by a decline in health and vitality of the race. At such times *renewal of youthful condition or a sort of rejuvenescence* is brought about by the process of *conjugation* between the individuals of different clones; the rejuvenescence[1] is brought about by a number of processes in which nuclear reorganisation and interchange of nuclear material occur between the two individuals which are descendants of different parents and therefore represent two different races. (Such nuclear reorganisation processes are *endomixis, hemixis, conjugation* and *autogamy*).

2. Sexual Reproduction

(d) **Conjugation** does not occur in regular succession in continuity but on the other hand it occurs only after a large number of generations by binary fission. Paramecia of the same clone do not conjugate. The *conjugants* belong to different clones. We will briefly describe conjugation in unimicronucleate species :

1. Feeding stops, 2. certain physiological changes occur, 3. the two conjugants contact by oral surface and adhere by their anterior ventral region due to a sticky secretion. The cytopharynx, cilia and trychocysts etc. differentiate, 4. the *macronucleus* disintegrates and is resorbed into the cytoplasm, 5. the micronucleus of each conjugant divides into two, then each of these micronuclei divides again forming *four* nuclei : of these two divisions one is a reduction division, 6. of these *four*, three micronuclei degenerate, the remaining one micronucleus divides into two unequal daughters—(i) a larger haploid *stationary* (female) *pronucleus* and (ii) a smaller haploid active *wandering* (male) *pronucleus.* 7. a *pre-oral cone* is formed in each conjugant near its mouth, 8. the *wandering pronucleus* of each migrates into the pre-oral cone and then the wandering pronucleus of one conjugant migrates

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[1] *Rejuvenescence,* to grow young again : to recover youthful character.

15

Locomotion in Protozoa

1. Describe the mechanism of locomotion in *Amoeba, Euglena, Paramecium* and *Monocystis.* (L. U. B. Sc. Pass, 1954)

2. Give an account of the organs and the mode of locomotion in *Amoeba, Euglena* and *Paramecium.*

Locomotion implies a *change in position of an animal.* Protozoa exhibit pronounced locomotory powers and except for the sessile forms, it is difficult to find a protozoan body in a stationary pose. It it amusing to watch the actively moving microscopic protozoa like *Amoeba, Euglena, Paramecium, Vorticella* and *Opalina* etc. on a slide under microscope. The free-living forms exhibit active locomotion while the parasitic forms have only a little aptitude and capability of moving about.

At least *four* different modes of locomotion are met with in Protozoa : (i) *pseudopodial locomotion* (ii) *ciliary and flagellar locomotion* (iii) *muscular movement due to myonemes and* (iv) *movements by the* undulating membrane as in trypanosomes.

I. Pseudopodial locomotion occurs in the class *Sarcodina.* The organellae employed for the locomotion are *pseudopodia* (temporary outpushings of the protoplasm) which are of four kinds : (i) **lobopodia** which are short and blunt (ii) **filopodia** are filamentous, anastomose slightly (iii) **rhizopodia** are filamentous and profusely anastomose forming a network round the shell and (iv) **axopodia** which have a well defined solid axial filament surrounded by a protoplasmic layer. The axopodia hardly exhibit any movements other than extension and contraction.

(i) **Lobopodia** or the 'lobose pseudopodia' are typically found in *Amoeba* and *Entamoeba* (trophozoite). *Amoeba* sends out protoplasmic projections or false feet (*pseudopodia*). One of the several pseudopodia outgrows all others and it is this larger pseudopod which marks the advancing end, the temporary anterior end of the organism. The tip of the advancing pseudopodium clings to the substratum. The amoeboid movement in *Amoeba* has been explained by the **change of viscosity theory** or **sol gel theory.** The successive steps in the amoeboid movement are (i) attachment of plasmalemma to substratum (ii) plasmosol at the anterior end of the body gelates (iii) plasmagel at the posterior end of the body solates and (iv) the plasmagel at the posterior end of the body contracts. During these steps the ectoplasm is pushed forwards forming a blunt projection or outgrowth, the endoplasm streams forward in the projection with the result that the entire body moves a bit forwards. The advancing pseudopodium assumes the shape of an ectoplasmic tube filled up with the endoplasm, the lateral walls are of plasmagel while inside is the plasmasol. (See figure no. 29) *Entamoeba* also has lobose *pseudopodia*.

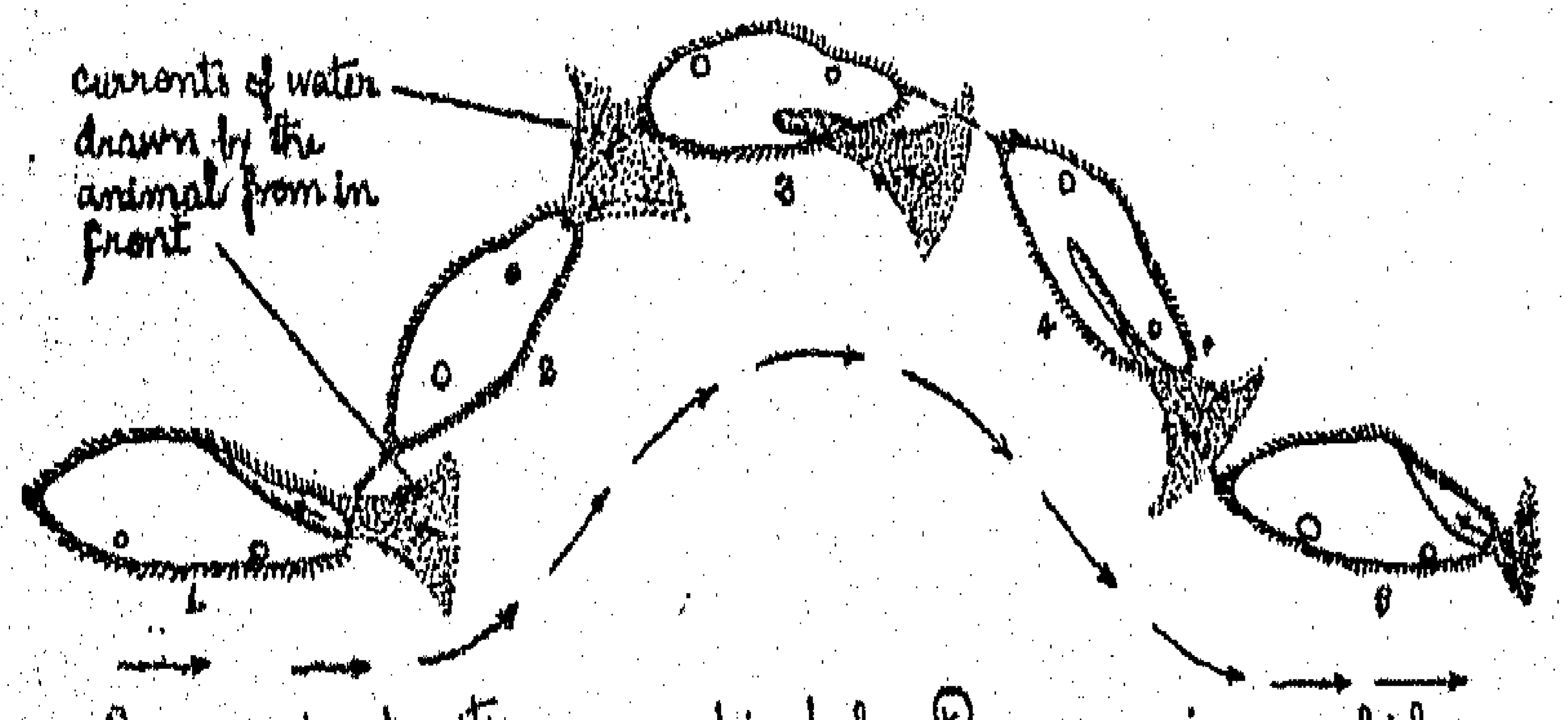
(ii) *Filopodia* are filamentous pseudopods which anastomose only slightly or not at all; these are found in radiolarians.

(iii) *Rhizopodia* are filamentous and anastomose frequently; they possess a protoplasmic cylindrical axis which is more solid than the surrounding granular protoplasm which undergoes constant streaming movements. The *filopodia* and the *rhizopodia* bring about rolling and creeping movements in Radiolaria and Foraminifera.

(iv) *Axopodia* are stiff protoplasmic filaments radiating outwards from the cell-body; these possess a solid axial filament surrounded by a thick layer of protoplasm and exhibit movements of contraction and extension. The axopodia are found in various Heliozoa e. g. *Actinophrys* (Fig. no. 18), *Artiodiscus* etc; these animals perform slow crawling movements upon the ends of the axopodia which become viscid.

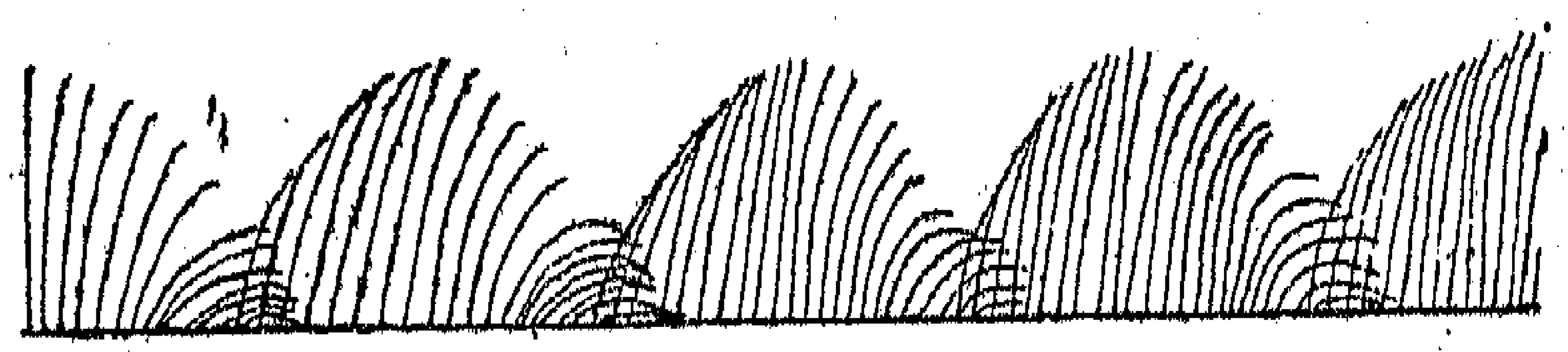
In the shelled Sarcodina *Arcella* and *Difflugia* slender pseudopodia are protruded out through the pylome (See fig. no. 13 and 15); while floating, the pseudopodia of these shelled forms keep swinging freely; the pseudopodium sticks to the substratum first and then contracts pulling forwards the entire body of *Arcella*.

II. Ciliary and Flagellar locomotion : Structurally cilia and flagella do not have much of difference except that the cilia are smaller and more numerous than the flagella. The cilia as well as flagella possess a straight central, probably fibrous core or *axoneme* surrounded by a straight or spiral *sheath*. The cilia are characteristic locomotory organellae found in the class **Ciliata** (subphylum Ciliophora) e. g. *Paramecium*, the entire body of which is uniformly covered over by very numerous cilia which beat in co-ordination and act as minute oars. The cilia are very small ('01") structures and perform 'ciliary beatings': the individual cilia bend along their length and strike the water producing a backwardly directed striking force; the force which moves the organism forward is a reactive force produced by the striking force, for 'every action has an equal and opposite reaction'. The water is struck posterolaterally and hence the animal moves forwards; the organism thus moves opposite to the direction of ciliary strokes.



Successive positions occupied by Paramecium while moving in a spiral path (After Jennings)

Fig. 68



Metachronous beating of cilia in a longitudinal row [AFTER VERWORN]

Fig. 69

The ciliary beatings in *Paramecium* are **metachronous** i. e. the forward cilia beat first and the cilia behind beat later, producing waves of ciliary movements very much like the movements observed in a crop of rice-field in a storm. The movement of cilium consists of an **effective stroke and a recovery stroke.** During the effective stroke, the cilium bends throughout its length as a rigid rod and strikes the water like an oar, pushing the water backwards (along the direction of stroke) and the animal forwards. During the recovery stroke the cilium swiftly resumes its original position due to elasticity of its sheath. The cilia of a transverse row beat at the same time i. e. *synchronously* while the cilia in longitudinal rows beat metachronously. The waves of ciliary beatings proceed from the anterior to the posterior side. The animal generally moves forwards and for this the cilia move backwards. When the animal moves backwards the direction of ciliary beatings also becomes reversed. While progressing forwards *Paramecium* keeps rotating on its longitudinal axis in a left spiral; this is *not* due to the oblique oral groove but because of the fact that the ciliary beatings are slightly directed towards the rightside instead of being disposed directly backwards.

The cilia of the oral groove beat directly backwards and with a greater force tending to turn the animal toward the aboral side. The tendency of the animal to roll over to the left coupled with another force tending to swerve the animal towards the aboral side results in a straight course while forming large spirals. The most important part of the ciliary mode of swimming in *Paramecium* is the *co-ordination of ciliary beatings* involved, which function is shared by the *elaborate neuromotor system.* The ciliary beatings probably occur due to some kind of contraction of protoplasmic sheaths. In case of *Opalina*, the cilia beat synchronously and the disc like body frequently turns on its edge. The free swimming *telotroch* of Vorticella which has an aboral band of cilia also swims by the ciliary beatings very much like *Paramecium*.

Flagellar locomotion is typically found in members of the class Mastigophora which may have one or more flagella. *Euglena* is a typical uniflagellate form; its flagellum is capable of bending and coiling movements; it can move in any manner.

According to **Lowndes**, the flagellum is always directed backwards and the series of spiral waves pass from its base to the tip with increasing amplitude producing two forces which act upon the anterior end of the animal,—one rotating the body on its long axis and the other gyrating it forwards along the direction of locomotion. The animal gyrates about the axis which marks the direction of locomotion. And that is why, *Euglena*, during the flagellar movement rotates on its long axis and follows a spiral path while swimming. The body remains inclined to the general direction of locomotion at an angle of 30°. The posterior end describes a much smaller circle than the anterior one.

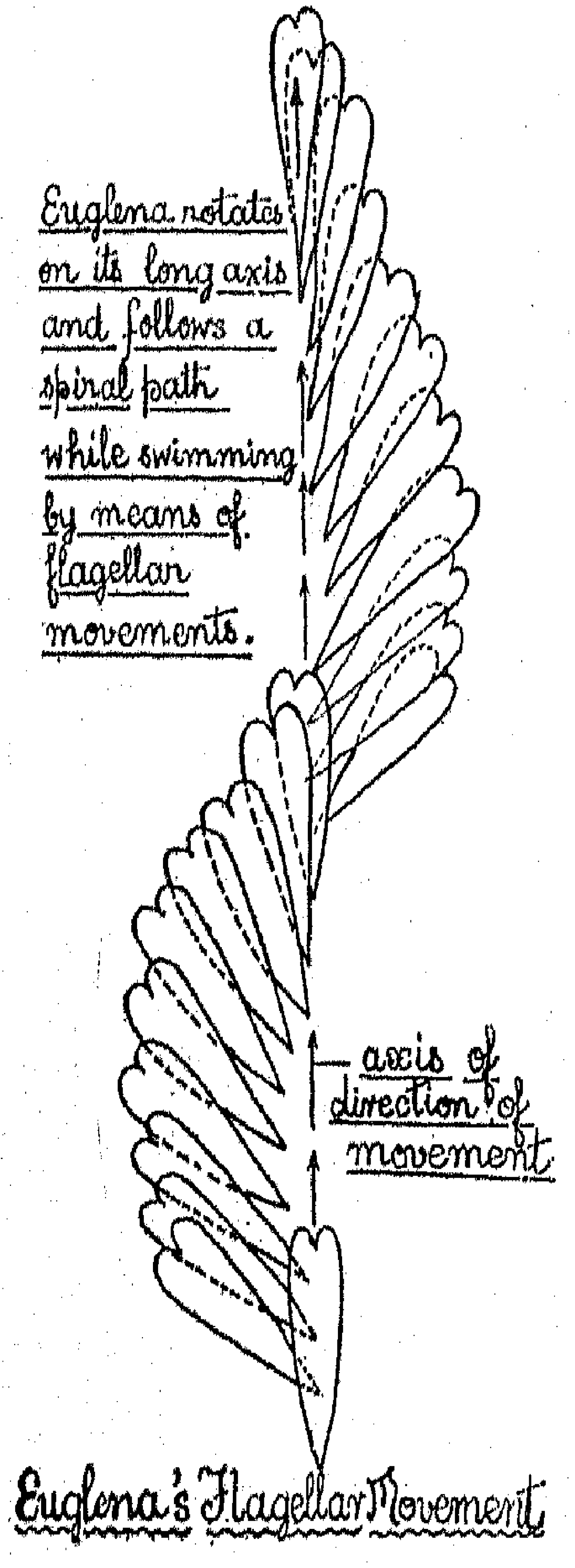
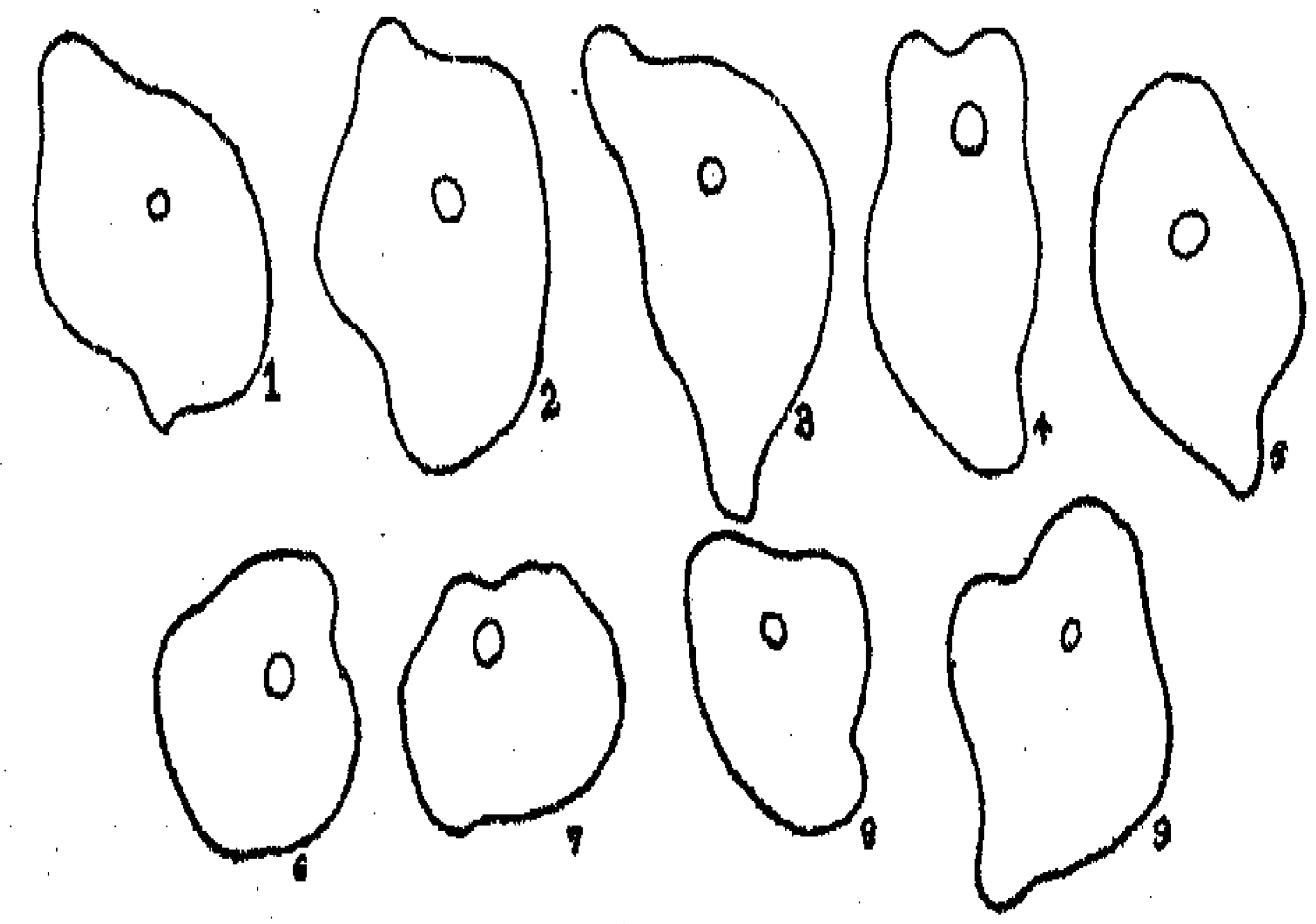

Euglena rotates on its long axis and follows a spiral path while swimming by means of flagellar movements.
axis of direction of movement
Euglena's Flagellar Movement

Fig. 70.

[Euglena sometimes moves by waves of contraction and expansion of pellicle which pass over the entire body somewhat like the manner of peristalsis. This is known as **metaboly** or euglenoid movement].

Amongst the *Dinoflagellata*, of the two flagella, one is longer and acts as a propelling organelle; in case of *Ceratium* (See fig. No. 5) there is a longitudinal groove in which lies a backwardly directed flagellum known as *pulsellum*; the pulsellum pushes the animal forwards.



Euglena showing changes of form during metaboly or euglenoid movements in which the animal undergoes slow worm like movements of contraction and expansion. The flagellum has not been shown as it could not be seen under ordinary conditions.

Fig. 71

In case of *Volvox*, the entire colony consisting of two hundred to fifteen thousand individuals swims as a unified whole due to the flagellar beatings. (See Fig. No. 1).

III. Muscular movements: in case of *gregarines* e. g. *Monocystis* (trophozoite), the innermost layer of cortex contains contractile elements or *myonemes* which act very much like the muscular fibres of higher animals. The body of the trophozoite performs slow movements of expansion and contraction very much like the euglenoid movements or metaboly found in case of *Euglena*. This movement of the trophozoite in *Monocystis* has been described as the '*gliding movement*'.

In case of the euglenoid movements of *Euglena*, the animal moves slowly due to peristaltic waves of contraction and expansion which pass over the body from its anterior to the posterior end. Probably the euglenoid movements are due to movements of the elastic pellicle, but the exact mechanism is not known.

IV. Movement by undulating membrane: in case of *Trypanosoma*, the flagellum is attached along most of its length to the wavy protoplasmic edge of the body which forms the **undulating membrane**. The undulating membrane helps in movements of the Trypanosome's body. The undulating movements push the animal forwards through the blood.

It may be added that the nature of the locomotor organellae found in the predominant phase of the life-history of a given protozoon forms the basis or the criterion of its classification. It is on this criterion (i. e. the nature of the locomotor organellae) that the phylum has been divided into four classes.

16

Nutrition in Protozoa

1. **How does *Euglena* take its nourishment? Compare its mode of nutrition with that of *Paramecium* and *Amoeba*.** (Agra, 1947, 1952)
2. **Describe the way some animals obtain their food by ciliary activity. Point out the relationship of this mode of feeding and the structure and habitat of animals.** (Agra, 1950 and 1953)
3. **Describe the structures associated with feeding in Protozoa.** (L. U. B. Sc. Prel. 1956)
4. **Write a short essay on 'Nutrition in Protozoa'.**

Nutrition literally implies the act of nourishing or feeding in layman's language. Nutrition actually includes not only food-intake or ingestion and absorption but it entails the entire process by which substances are made use of by the cell body as nutrient substances or food. The Protozoa derive their nourishment by four different methods: I **Holozoic** or **Zootrophic** II **Saprozoic** or **Saprophytic** III **Holophytic** or **Autotrophic** and IV **Mixotrophic.**

I. Holozoic nutrition: the food usually consists of solid particles; in this mode of nutrition, other animals or plants are used as food substances; other solid organic food may also be ingested. The food consists of bodies of other organisms which may be living at the time of ingestion, or may have been killed recently or may have recently died. The whole process consists of *ingestion, digestion, assimilation and egestion.* Holozoic nutrition occurs, for example in *Amoeba* in which ingestion occurs by any one of the following methods: (i) *Import* (ii) *circumfluence* (iii) *circumvallation* and (iv) *invagination*[1] (See fig. No. 30). The pseudopodia are the principal orgnellae in ingestion and they may be blunt lobe like (lobose) e. g. in *Amoeba proteus* and *Arcella*, (b) long and pointed with a central axial filament (*axopodia*) as in *Actinosphaerium* in which they bend for capturing the food (c) thin and filamentous (*rhizopodia*) as in Foraminifera e. g. *Polystomella*. The rhizopodia branch and anastomose strongly forming a network of protoplasm round the protozoon's shell; when food is found within approach, the anastomosing pseudopodia form a small mass of protoplasm in which the food is digested; the *rhizopodium* has in its outer part, granular protoplasm which keeps flowing from the tip to its base in the body and carries the digested food into the endoplasm. Several rhizopodia co-operate and entangle the prey. In some cases digestion also occurs in the rhizopodia by the enzymes secreted therein. The *filopodia* are filamentous, fine threadlike which become branched near their ends but do not anastomose or coalesce except at their proximal ends.

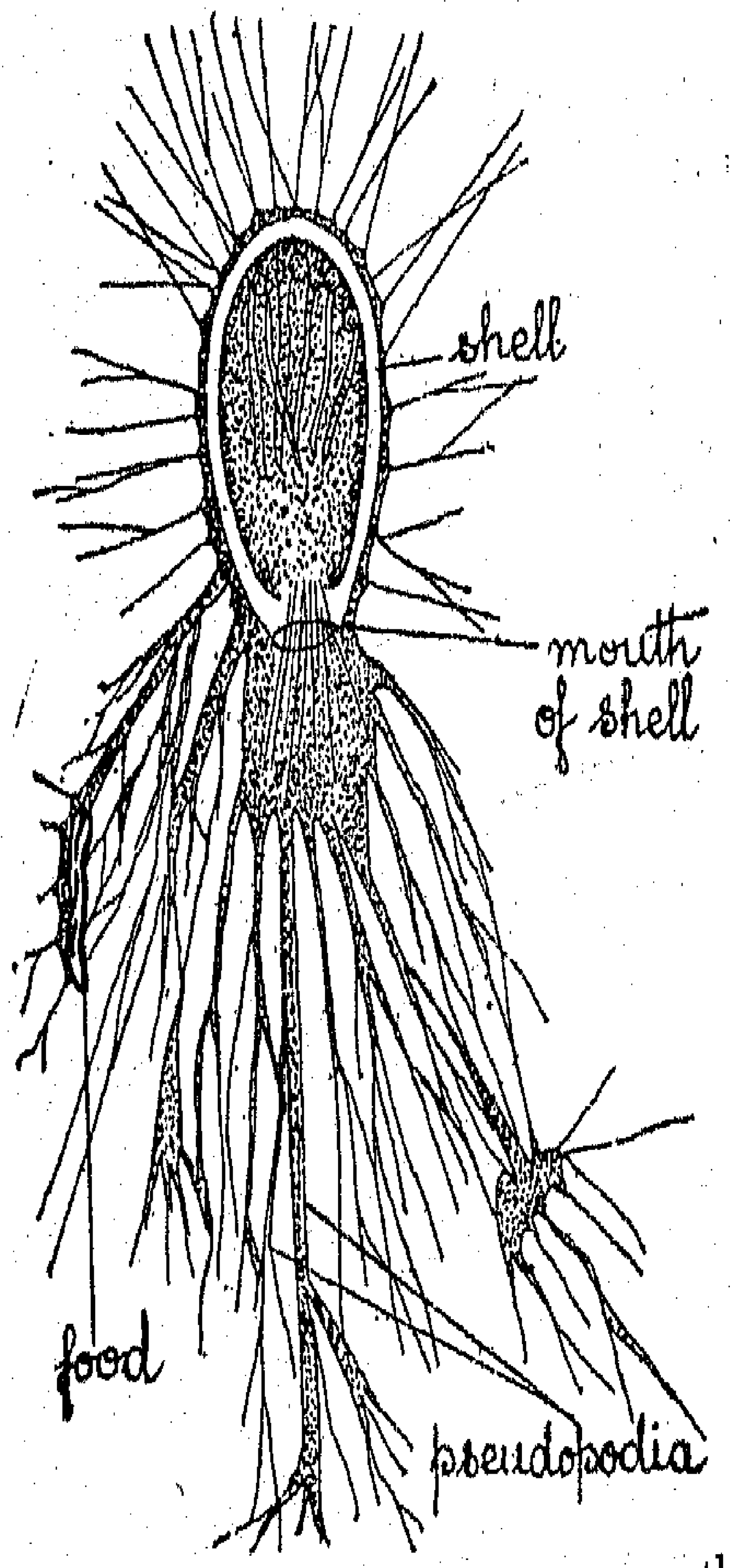


Fig. 71A. Allogromia showing food capture by anastomosing rhizopodia. (After Camb. Nat. History, from Woodruff).

The *axopodia* of Heliozoa and the rhizopodia of Foraminifera usually paralyse and kill the prey prior to its ingestion. The pseudopodia secrete and administer toxic substances to the prey which adheres to the viscous protoplasm.

Ingestion or *food capture* is assisted by various organellae e.g. the *cilia* of ciliates, *flagella* and *collars* of *choanoflagellates* (See fig. 8), the ingestatory apparatus (of some Ciliophora) and the *tentacles* of Suctoria (*Ephelota*) etc.

The ciliary beatings produce ciliary currents of food in *Paramecium* as well as in *Vorticella*. The animal has to filter a large amount of the surrounding water to get food particles. The mode of nutrition in paramecium is also holozoic. After being collected, the food-particles are transferred to the cytostome and are then driven down the cytopharynx by the

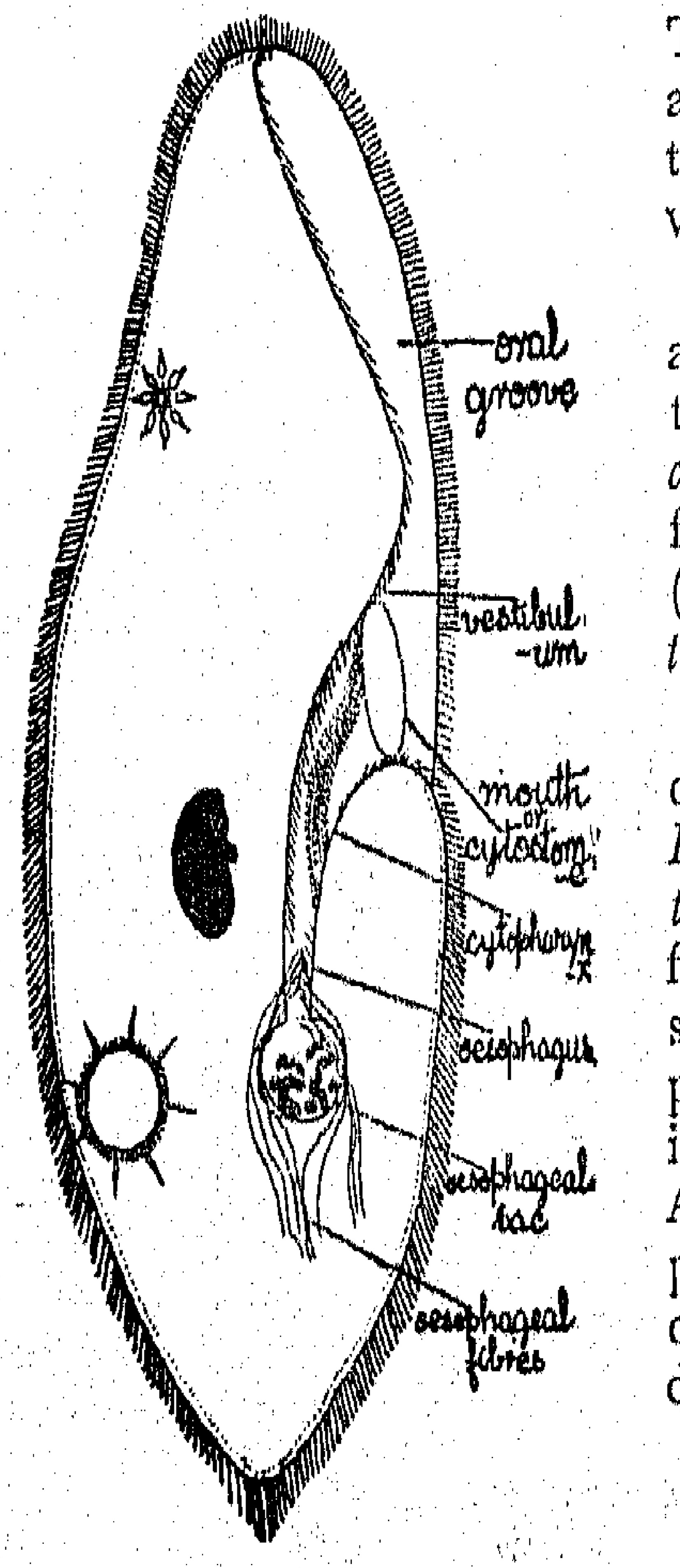


Fig. 72. Diagram showing the oral groove and the digestive tract of Paramecium.

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[1] See pages 172 and 173 and fig. 150 of 'A textbook of Invertebrate Zoology' by **Murli Manohar Saxena** for a detailed account of all these four processes].

action of specialised cilia. This method of food collection by sieving out food particles from the external medium is known as *filterfeeding*. In case of *Paramecium*, the oral groove contains strong cilia which set up a 'feeding current of water' towards the groove and the gullet. The ciliature of the wall of ingestatory apparatus drives the food particles inwards into the oesophageal tube at the tip of which the food particles along with some water are formed into a food vacuole. The food vacuoles are formed in succession one after another and in the endoplasm they undergo 'cyclosis' during which digestion and absorption occur.

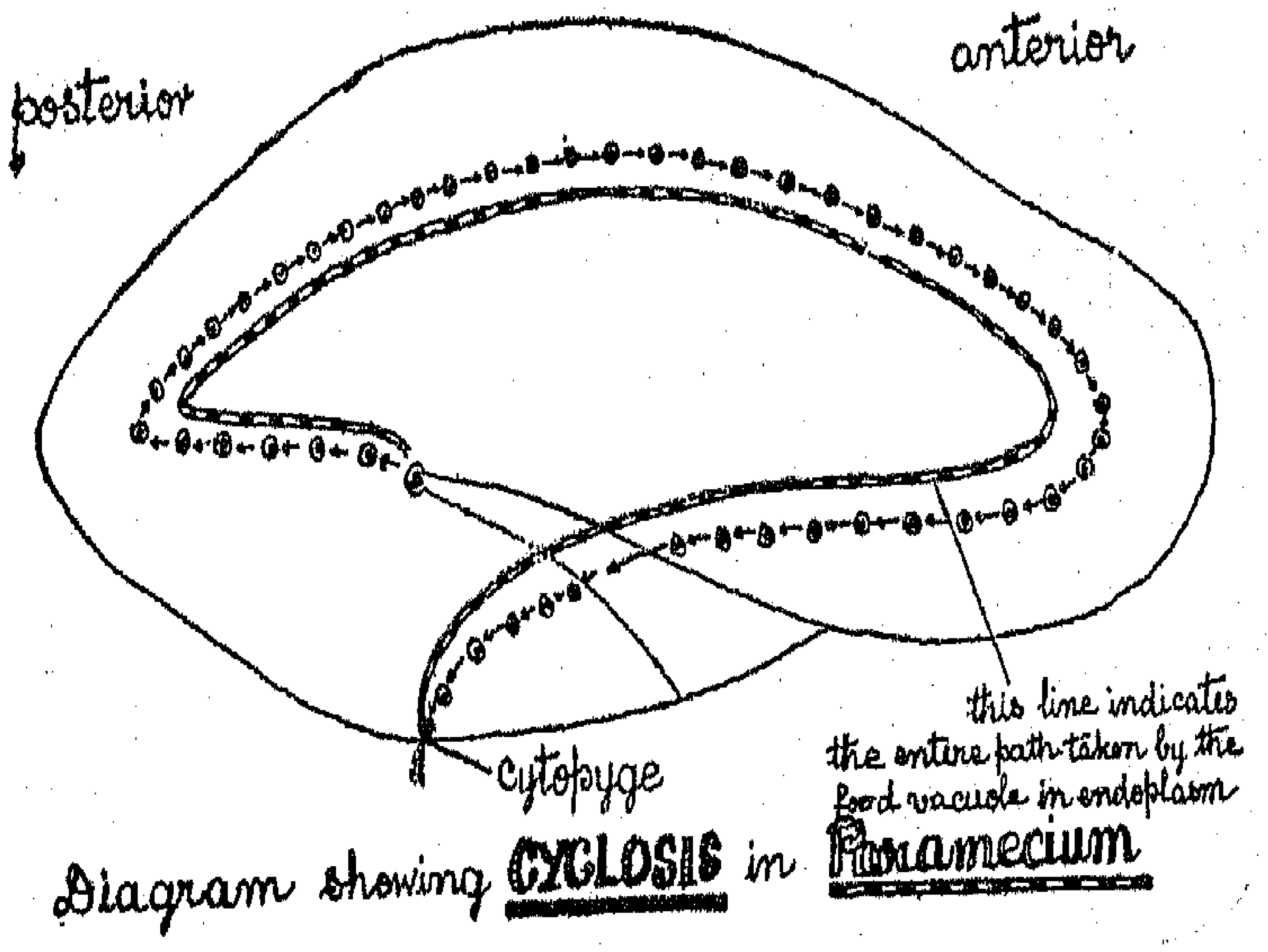
posterior
anterior
this line indicates the entire path taken by the food vacuole in endoplasm
cytopyge
Diagram showing CYCLOSIS in Paramecium

Fig. 73

Vorticella also has specialised ciliature and feeds holozoically by filter feeding. A holotrichus ciliate *Didinum* has an expansible cytostome situated at the tip of a small probosics. *Didinum* feeds holozoically upon Paramecium. The hollow tentacles of *Suctoria* have swellings or knobs at their ends which adhere to the prey and secrete a toxic substance which kills it. The prey is pierced by the tentacles and its protoplasm is sucked by the suctorian through the tubular tentacles.

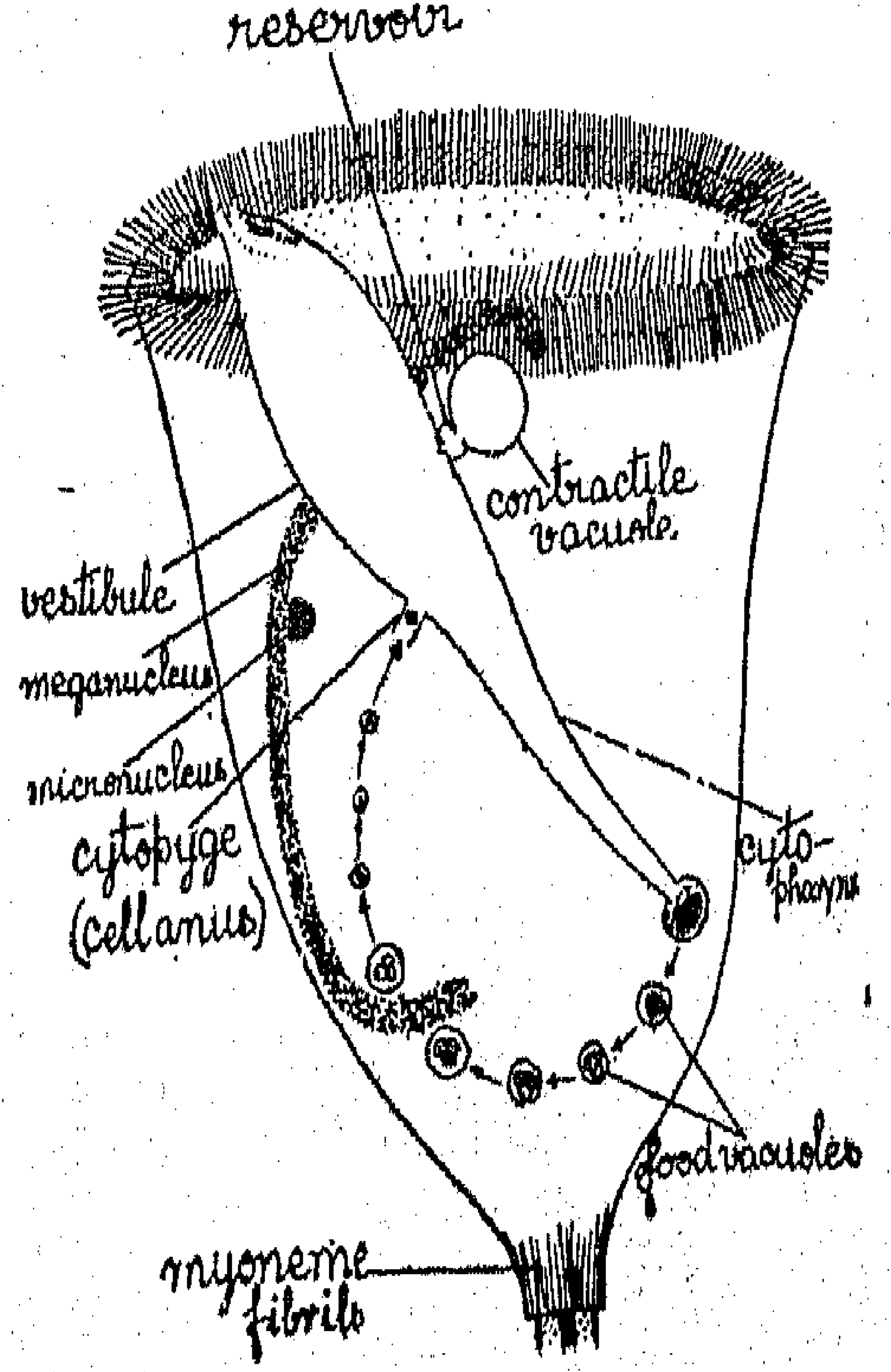

Fig. 74. Vorticella showing the ingestatory apparatus.

In all cases of holozoic feeding some of which have been mentioned above, food vacuoles are formed into which enzymes very much like those of other multicellular animals are secreted by the surrounding endoplasm. The food vacuole shows at first an *acidic phase* and later assumes an *alkaline phase* during which most of the digestion occurs. In the acidic phase, the prey taken alive is killed. **Pepsin-like proteases** digest proteins in the acidic medium. Proteolytic **trypsin** acts in the alkaline medium. **Amylases** convert starch into sugar. **Cellulase** is found in hypermastigid flagellates and digests cellulose. Fat is digested in amoeba. Through the wall of food-vacuole, absorption occurs and then assimilation occurs in endoplasm. Excess digested food is kept in reserve. The undigested portions and the indigestible residue are egested out through a temporary or in some cases a permanent **cytopyge**. Small flagellates, ciliates, diatoms, rotifers, algae, bacteria, yeast cells and other micro-organisms are taken by various holozoic protozoa.

II. Saprozoic nutrition (Saprophytic)—This method of feeding implies *absorption of dissolved organic nutrient material* from the external medium by osmosis through the general body surface or through some specialised region of the body. The food may consist of dissolved proteins and carbohydrates resulting from the disintegration of plant and animal bodies or inorganic salts of nutritive value. Most of the parasitic protozoan forms feed saprozoically e. g. *Monocystis*, *Plasmodium*, *Opalina*, and *Giardia* etc. *Entamoeba histolytica* and *Balantidium coli* are parasitic but nourish themselves holozoically in addition to their saprozoic habit. Many free-living forms also nourish themselves saprozoically e.g. *Euglena*.

III. Holophytic or **Autotrophic mode of nutrition** is secured very much as in plants; the holophytic forms build up complex organic substances out of simple ones with the help of *solar energy* and *pigments* found in their cytoplasm in the *chromatophores* or **chromoblasts** (Chlorophyll, Xanthophyll etc.) The chromatophores are intracellular organellae having chlorophyll which is the same green colouring matter as is found in plants. *Chlamydomonas* and *Volvox* (Phytomastigina) are exclusively holophytic ahd synthesize their complex food materials out of carbon dioxide, water and certain dissolved minerals in presence of sunlight. In the holophytic nutrition, true photosynthesis occurs in protozoa very much like that of plants. The end product of photosynthesis in protozoa is **starch** or **paramylum** (which is allied to starch but does not stain black when treated with iodine).

IV. Mixotrophic mode of nutrition: Protozoa which do not thrive exclusively by one single mode of nutrition and instead have combined mode of nutrition are said to possess a '*mixotrophic mode of nutrition*'; this is typically found in *Euglena*, which loses chlorophyll when kept in dark and subsists by absorbing dissolved nutrient material from the external medium through its general body surface i. e. nourishes by the saprozoic mode of nutrition. Thus Euglena combines the holophytic mode with the saprozoic mode of nutrition and this dual or 'mixed' method of deriving nutriment is known as *mixotrophic mode of nutrition.*

Six kinds of reserve food materials are found in Protozoa: (i) glycogen (ii) paramylum (iii) leucosin (iv) oil droplets (v) fat bodies and (vi) volutin granules.

Relation between mode of feeding and structure and habitat of animals.

There are clear and well defined correlations between the habitat and the available food of an animal, the feeding mechanism and the digestive processes and enzymes. The protozoa are all 'fine particle freeders' which are mostly aquatic, sessile or free-living, feeding is mechanical with a reduced selective power, there are no organellae for mastication, no salivary glands, small zooplankton, phytoplankton and other organic matter serve as food and selection if any is exercised on mechanical grounds and very little on biochemical characters. Due to aquatic habit, the feeding amongst the protozoa occurs by means of *pseudopodia,* cilia and flagella etc. In some holophytic forms and in parasites saprozoic method prevails. Ciliary feeding is found in *Paramecium* and *Vorticella* etc.

The presence in **ciliary feeders** of the same general kind of *specialised ciliature, ingestatory apparatus* consisting of *vestibule, cytopharynx* and *gullet* ending blindly in the endoplasm, formation of *food vacuoles* and similar modes of defaecation through the cytopyge in various forms such as *Paramecium* and *Vorticella* at once hits at the existing correlation between their mode of feeding (the *ciliary mode*) and structure and habitat of animals. Secondly, when *physically* as well as chemically the food taken by the various ciliary feeders is more or less of the same kind, a close similarity between their modes of digestion and the available enzymes is also naturally found.

Let us now compare the modes of nutrition in *Euglena, Paramecium* and *Amoeba* which are all aquatic in habit.

Euglena	Paramecium	Amoeba
1. The mode of nutrition is *mixortrophic*: i. e. *holophytic* as well as *saprozoic.*	1. The mode of nutrition is *holozoic*; i.e. solid food is ingested.	1. The mode of nutrition is *holozoic.*
2. Photosynthesis occurs in sunlight.	2. Photosynthesis does not occur.	2. Photosynthesis does not occur.
3. No specialised organellae of feeding are found; the cytopharynx which is present is not used for ingestion of food.	3. Specialised organellae of feeding are *cilia* which create a feeding current; a highly complicated *ingestatory apparatus* equipped with specialised ciliature is found. The oral groove, the vestibule, the cytostome, the cytopharynx and the oesophageal tube are all differentiated and specialised for ingestion; they together constitute the ingestatory apparatus.	3. The *pseudopodia* (*lobose*) are the specialised oaganellae for ingestion (as well as for locomotion).
4. The region of food-intake is not fixed.	4. The region of food-intake is fixed; ingestion always occurs through cytopharynx.	4. The region of food intake is not fixed; it may occur at any point on the body-surface.
5. Dissolved food is taken.	5. Dissolved food is not taken mostly.	5. Dissolved food is not taken.
6. The food does not contain solid particles. Carbon dioxide, water and sunlight energy are utilised in autotrophic (holophytic) nutrition while dissolved organic matter is utilised in the saprophytic mode of nutrition.	6. The food consists of small solid particles; bacteria, yeast cells and other micro-organisms form the food.	6. The food consists of small solid particles: minute protozoa, algae, rotifers, bacteria and diatoms. Small living flagellates, ciliates: *paramecia* and small aquatic plants *Oscillaria* etc. are also ingested.

Euglena	Paramecium	Amoeba
7. Pseudopodia are never formed and no ingestion occurs: import, circumfluence, circumvallation or ingestion etc. are not at all found.	7. During ingestion, the ciliary tracts of the oral groove drive a current of water loaded with food particles. The ciliary tracts drive the food particles down to the cytostome wherefrom they are taken into the cytopharynx, oesophagus and lastly in the oesophageal sac which has a fine elastic membrane. This sac having accumulated food particles is released into the endoplasm as a food vacuole.	7. Food is ingested by import, circumfluence, circumvallation and invagination; in the second and the third of these devices pseudopodia or protoplasmic processes form a *food-cup.*
8. Food-vacuoles are not formed.	8. Food-vacuoles are always formed.	8. Food vacuoles are always formed.
9. No question arises of *cyclosis.*	9. The food vacoules move in the cytoplasm in a definite course known as *cyclosis.* This ensures a uniform distribution of nutrition.	9. The food vocuoles move inside the endoplasm with cytoplasmic streaming during which digestion and absorption occur. Uniform distribution of nutrition is ensured by such movements. The course of movement of food vacuoles is not fixed and no *cyclosis* occurs.
10. The food vacuole is not found.	10. The food vacuole is first acidic and then it becomes alkaline.	10. The food vacuole is at first acidic and later on it becomes alkaline.
11. Dissolved excretory substances are passed out through the general body-surface.	11. A definite **cell-anus** or **cytopyge** is found behind the oral groove on the oral side for egestion. Waste residue is passed out through the cytopyge. The place for egestion is thus fixed.	11. Egestion occurs at any point of the body surface by a temporary rupture or pore in the plasmalemma.
12. Reserve food is stored in the form of **Paramylum** a polysaccharide closely allied to starch. Probably reserve proteins are represented by the *phrenoids.*	12. Reserve food consists of fat-globules, lipoid granules, carbodhydrates, proteinaceous chromidia and volutin granules.	12. Aminoacids may be found in the form of crystalline inclusions. Other reserves may also be found.
13. Holozoic nutrition is not found.	13. Holozoic mode is the usual mode of nutrition.	13. Holozoic mode of nutrition is common.

17

Reproduction in Protozoa

1. **Write all you know about the reproductive processes in the protozoan types you have studied.**
(L. U. B. Sc. Pass, 1949)

2. **Describe briefly the methods of reproduction in the Protozoa.**
(L. U. B. Sc. Pass, 1959)

3. **Write a short essay on asexual reproduction in Protozoa.**
(L. U. B. Sc. Prel. 1959)

Protozoa reproduce **asexually** by (i) *binary fission* (ii) *multiple fission* (iii) *budding* (iv) *plasmotomy* (v) *colony formation and encystment*; and **sexually** by (i) *syngamy*, (ii) *conjugation* and (iii) *automixis* and (iv) *endomixis*.

Asexual Processes

(*i*) In *binary fission*, the parent protozoon divides into two approximately equal and similar daughters which grow into full fledged adults. The nucleus divides amitotically or mitotically and the cytoplasm divides by simple fission. Depending upon the mode of fission, the *binary division* may be of four kinds: (*a*) **Ordinary** *e. g. Amoeba, Arcella* and *Euglypha*, (*b*) **transverse** *e. g. Lophomonas, Trichonympha* and most ciliates e. g. *Paramecium*, (*c*) **longitudinal** *e. g. Euglena* and most flagellates and (*d*) **Oblique** as in Dinoflagellates e. g. *Ceratium*.

(*ii*) In the *multiple fission*, the nucleus undergoes a series of divisions followed by the division of the body into as many parts as there are nuclei; it may be of two types (*a*) repeated binary fission may occur in the parent nucleus as in Foraminifera and Radiolaria (*b*) the parent nucleus divides into many nuclei simultaneously as in *Plasmodium*.

[**Schizogony** is the term applied to the multiple fission during which many organisms are formed in a single host; **gamogony** is the term applied to the multiple fission leading to the formation of gametes; **sporogony** is the multiple fission of zygote leading to the formation of spores. These three stages are found in the life-cycle of **Sporozoa**].

(*iii*) In **budding,** cytoplasmic projections, internal or external, each carrying a daughter nucleus arise, from the parent body and for a time remain attached to it; these outgrowths are known as **buds** each of which after detachment from the parent body, develops into a full-fledged adult; this process is known as

budding and is of two types: (*a*) *exogenous budding* in which the buds are formed outside the cell-body as in *Endamoeba patuxent*, *Noctiluca* and *Ephelota*, a suctorian (*b*) *endogenous budding* or *internal budding* which implies formation of buds within the cell body. Endogenous budding is less common in Protozoa than the exogenous budding. Endogenous budding occurs in Testacea (*Arcella*), Gregarines and some Suctoria e. g. *Acineta tuberosa* in which the buds develop in a brood cavity; the buds in the brood cavity assume the form of ciliated embryos which after their escape from the parent body, develop into adults. (See fig. 52 on page 51).

(*iv*) **Plasmotomy** is the fission of a multinucleate protozoon (such as *Opalina*, Actinosphaerium) to form multinucleate offsprings by division of the cytoplasm without relation to that of the nuclei. It is usually binary but occasionally takes place by budding or its multiple.

A cell-body containing many nuclei is known as *plasmodium*. The division of such a plasmodium or a multinucleate protozoan into two or more multinucleate bodies without any fresh nuclear division is known as *plasmotomy*. The nuclei become distributed in groups in a number of cytoplasmic masses. Thus Plasmotomy is an asexual reproduction in which cytosomic and nuclear divisions do not coincide, the former is over delayed. After plasmotomy, the nuclei in the resulting cytoplasmic masses divide and each mass becomes a daughter individual with the requisite number of nuclei and other structures. Plasmotomy occurs in Myxosporidia, Foraminifera and Protociliates (*Opalina*).

(*v*) **Colony-formation**: When incomplete fissions occurs so that the daughters remain in vital continuity with the parent, a compound organism consisting of a number of connected units known as zooids is formed; the whole compound organism with the zooids is known as a **colony.** In almost all orders of the Protozoa, some kind of colonies are formed which may be categorised into five main types: In the (*i*) **catenoid form** the cell-bodies are arranged in a straight line and the colony is formed in a linear formation e. g. *Ceratium*, *Polkyrikos*, in the (*ii*) **arboroid form**, the colony is like the branching of a tree e. g. *Carchesium*, *Dinobryon*, in the (*iii*) **discoid form**, the colony is flat and rounded e. g. *Gonium* and *Proterospongia*, in the (*iv*) **spheroid form**, the colony assumes the form of a sphere e. g. *Volvox* (See fig. 27), *Eudornia* and *Pandorina* and in the (*vi*) *gregaroid form*, the colony is a loose associa-

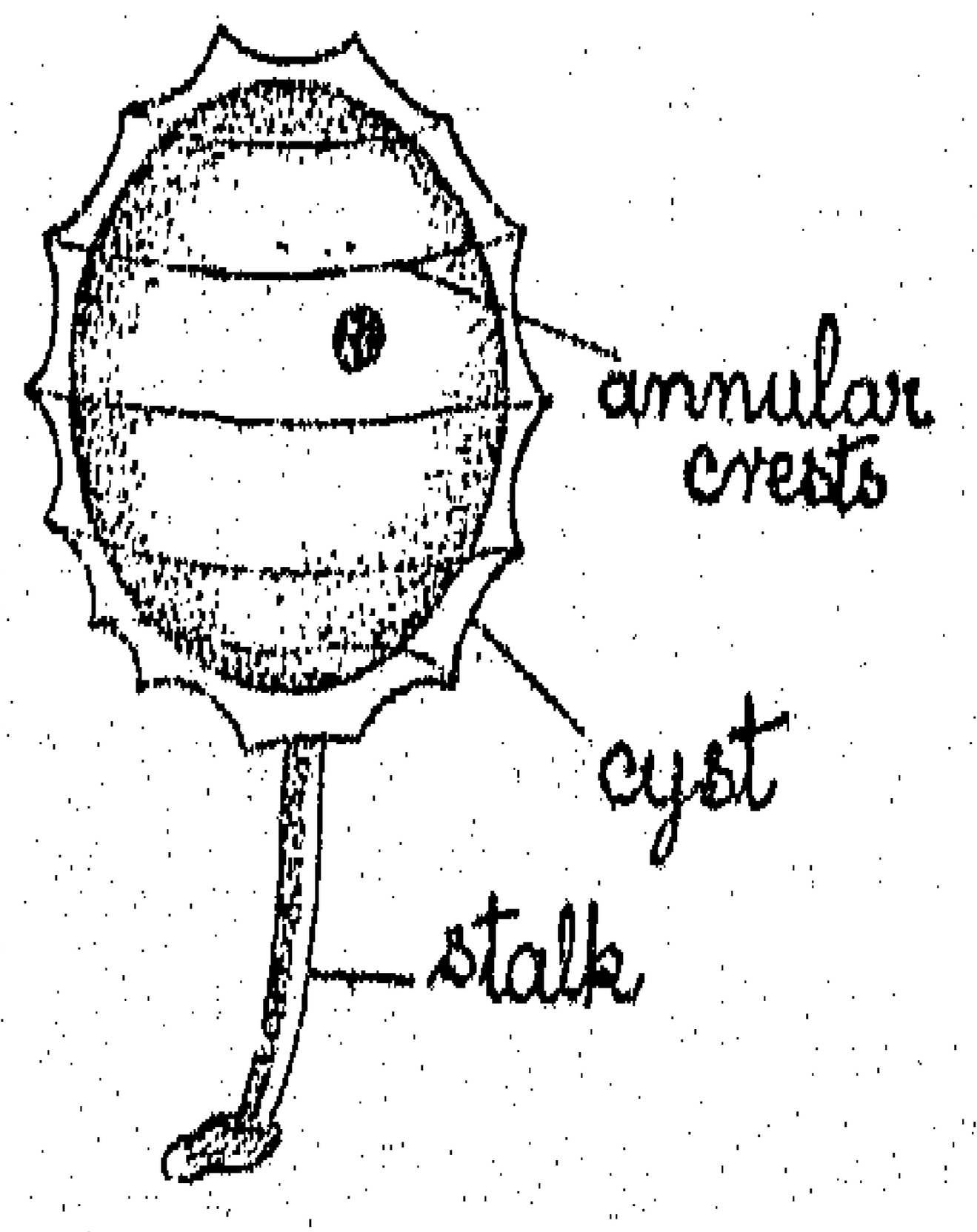

Fig. 75. Encystment in Podophrya (After Collin).

tion of individuals as seen in the life-history of some Sarcodina; small amoebulae sometimes gather and form loose associations.

(*vi*) **Encystment** the animal secretes a cyst round itself and the daughter individuals are formed inside the cyst; when the cyst ruptures, the daughters are liberated e. g. *Bursaria*, a free-living form under the Spirotricha, class **Ciliata.** Encystment also occurs in *Podophrya* (a suctorian).

Sexual Reproduction

Sexual reproduction involves participation of two individuals which exchange nuclear material, or form a *fusion nucleus* as a result of complete union of two nuclei.

Syngamy is a term used for the union of two nuclei, accompanied by the fusion of such cytoplasm as each may possess. The *energids*[1] participating in the syngamy are called *gametes.* The *gametes* when smaller than ordinary energids of the species and formed by fission are known as *mcrogametes*; when the gametes are as large as, or larger than the ordinary energids of the species which are not formed by special fissions are called *hologametes.* **Syngamy** is of three kinds: (i) syngamy between like gametes is known as *isogamy*; isogamy occurs in foraminifera (e. g. *Polystomella*), in phytomonadina e. g. *Noctiluca* in which isoswarmers are formed, in Sporozoa e. g. *Monocystis*; in *Chlamydomonas* also isogamy occurs. (ii) syngamy between unlike gametes is known as *anisogamy* which is more widespread in protozoa and occurs in sporozoa, radiolaria and a few colonial flagellates e. g. *Volvox, Eudorina* and *Pandorina.* Microgamete is smaller, more numerous and motile. Macrogamete is large, less numerous and non-motile. In anisogamy, the female gamete (*macrogamete*) is larger than the male (*microgamete*). In *Volvox,* the female gamete is as large as the adult and hence the gamete is a *hologamete*; in it the anisogamy is therefore termed *oogamy.*

Syngamy in which the two full sized ordinary individuals unite is known as *hologamy*; an example of hologamy is offered by *Copromonas* (Order Euglenoidina). Isogamous as well as anisogamous **syngamy** always occurs between the offspring of different parents and is therefore described as **exogamous.** Since the male and female gametes are produced by distinct parents, the protozoa are said to possess 'sex'. It is remarkable however that it is only rarely that the sexes can be distinguished by other features.

Besides (i) **syngamy,** the other sexual process in Protozoa are (i) **conjugation** (ii) **automixis** and (iii) **endomixis.** In conjugation (See page 86) e. g. that of *Paramecium,* the cytoplasm becomes enriched by the breakdown of the micronuclear and

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[1] *Energid* is the term employed for any nucleus with its cytoplasm; the energid is that which constitutes the body of a protozoon or a cell; many energids constitute the metazoan body.

meganuclear material; the cytoplasm of the different paramecia becomes intermingled. A fresh meganucleus is formed. The significance of this process has already been described. Conjugation is confined to two groups Euciliata and Suctoria. *Isogamous conjugation* is found in ciliates: the conjugants are *similar* and belong to vegetative phase. In anisogamous conjugation, one of the conjugants is smaller than the other; the conjugants are not always in vegetative phase: they undergo preconjugative fissions as a result of which one small and one large individuals are formed; such an anisogamous conjugation occurs in *Vorticella.* In Paramecium, the conjugation is isogamous.

(iii) **Automixis** implies fusion of two gametic nuclei derived from the same parent nucleus and is of three kinds: (a) *Autogamy* in which the parent nucleus divides into two gametic nuclei which lying in the same cell fuse to form the synkaryon; the cytoplasm of the parent cell does not divide; it occurs in many sporozoa. In *Paramecium aurelia* also autogamy occurs: the animal undergoes all the processes of conjugation but only one individual takes part in the process and it provides both the pronuclei. In *Actinophrys,* a sort of automixis known as (b) **paedogamy** occurs in which the cytoplasm as well as the nucleus of the parent cell-body divide and the two daughter cells become enclosed in a common cyst and later on fuse; this cell formed as a result of fusion divides into two and thus two individuals are formed; (c) **cytogamy** occurs in *Paramecium caudatum* in which neither the cytoplasm nor the nuclear material is exchanged between the two participants: only a fresh macronucleus is reorganised which replaces the original fatigued one. Cytogamy differs from syngamy in the fact that in it there is no breakdown of the membrane between the two animals and there is no nuclear material interchanged between the two; cytogamy differs from autogamy in that the two animals are in contact with each other.

[**Endomixis** which may be a specialised form of autogamy doubtfully occurs in *Paramecium aurelia*; it resembles conjugation in that a new meganucleus is formed from micronuclear material but differs from it in that it is carried out by one *paramecium* only, there is no meiosis or fusion of pronuclei and hence no synkaryon is formed. Endomixis is a sort of nuclear reorganisation process or a rearrangement of the internal substance of the same individual. *Hemixis* in *Paramecium,* is also an aberrant[1] behaviour of the meganucleus independent of cell division or syngamy. The meganucleus may divide providing the animal with two meganuclei for a short time or it may protrude masses of nuclear material into the cell; hemixis involves macronuclear reorganisation changes in Paramecium irrespective of any micronuclear activity.[1]

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[1] [*Aberrant,* having characteristics not strictly in accordance with type].

To sum up it may be stated that the simpler forms amongst the Protozoa mostly reproduce asexually. Reproductive phenomena assume great complexity in Sporozoa in which the life-cycle involves both asexual and sexual processes (e. g. in *Plasmodium*, see fig. 60). The Sporozoa are parasitic and need an enormous number of offsprings in their infective phases in order to meet large scale mortality; this is made good in Sporozoa by special multiplicative processes: *schizogony* and *sporogony* besides the intervening *gamogony*.

The Protozoa also furnish a valuable clue to the probable stages in the 'evolution of sex' as seen in the series *Gonium*, *Pandorina*, *Eudorina* and *Volvox*[1] (class Mastigophora, order Phytomonadina).

Reproduction in Protozoa is mostly a kind of cell-division and mostly lacks 'embryonic development' but still a start in this direction is indicated by the presence of brood pouch in the suctorian *Acineta* (See fig. No. 52) in which 'ciliated embryos' are formed inside the brood-cavity.

Regular alternation of generations as well as *dimorphism* (e. g. *Polystomella*) are met with in Protozoa. During the course of their life-history some of the protozoa show remarkable changes of body form e. g. *Trypanosoma*; thus some of them show polymorphism also.

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[1] [For details of evolution of sex in Protozoa see pages 68, 69 of 'A Text Book of Invertebrate Zoology by **Murli Manohar Saxena** (1963 Edition).]

18

Protozoa and Disease

The Protozoa are of considerable economic importance as many of them cause serious diseases in man as well as his fish, poultry and cattle. Except Suctoria, all classes of the phylum have a number of pathogenic forms.

Entamoeba histolytica is a parasitic amoeba causing 'amoebic dysentery' in man. Amongst the Mastigophora a polymastigid form *Trichomonas vaginalis* is found in the vagina of many ladies and causes *leucorrhea* and *vaginitis*. Protomonads *Trypanosoma* and *Leishmania* are extremely important blood flagellates of man. *Trypanosoma gambiense* causes the *Gambian Sleeping Sickness* in man in Central Africa. *Trypanosoma rhodesiense* causes the more virulent Rhodesian Sleeping Sickness in man in the South eastern coasts of Africa. *Trypanosoma cruzi* causes the American Chaga's Disease mostly amongst children. *Trypanosoma brucei* causes the serious *Nagana* disease in African domestic animals. *Trypanosoma evansi* causes the well known *Surra* a fatal disease occurring in the Indian domestic animals. *Leishmania donovani* causes **Kala-azar** or **Visceral Leishmaniasis** in India, Europe, Africa, South America and China in man. *Leishmania tropica* causes *Oriental Sore* or **Cutaneous leishmaniasis** in man in Africa, India, Europe, Australia and Russia.

Amongst the Euciliata *Balantidium coli* causes the **balantidial dysentery** in man.

Greatest number of pathogenic forms however belong to the class **sporozoa**. *Plasmodium*, the malaria parasite of man is transmitted by the female *Anopheles* mosquito. The four important species of *Plasmodium* are (i) *P. vivax* which causes the **benign tertian** in which the death-rate is low, (ii) *P. falciparum* causes the **malignant tertian** which causes maximum death, (iii) *P. ovale* causes the **mild tertian fever** and (iv) *P. malariae* causes the **quartan malaria.**

Bobesia begimena causes the 'red water fever' or **texas fever** in cattle; it is also a blood-parasite of man (order Haemosporidia). Parasites belonging to the order Myxosporidia cause serious epidemics in fishes.

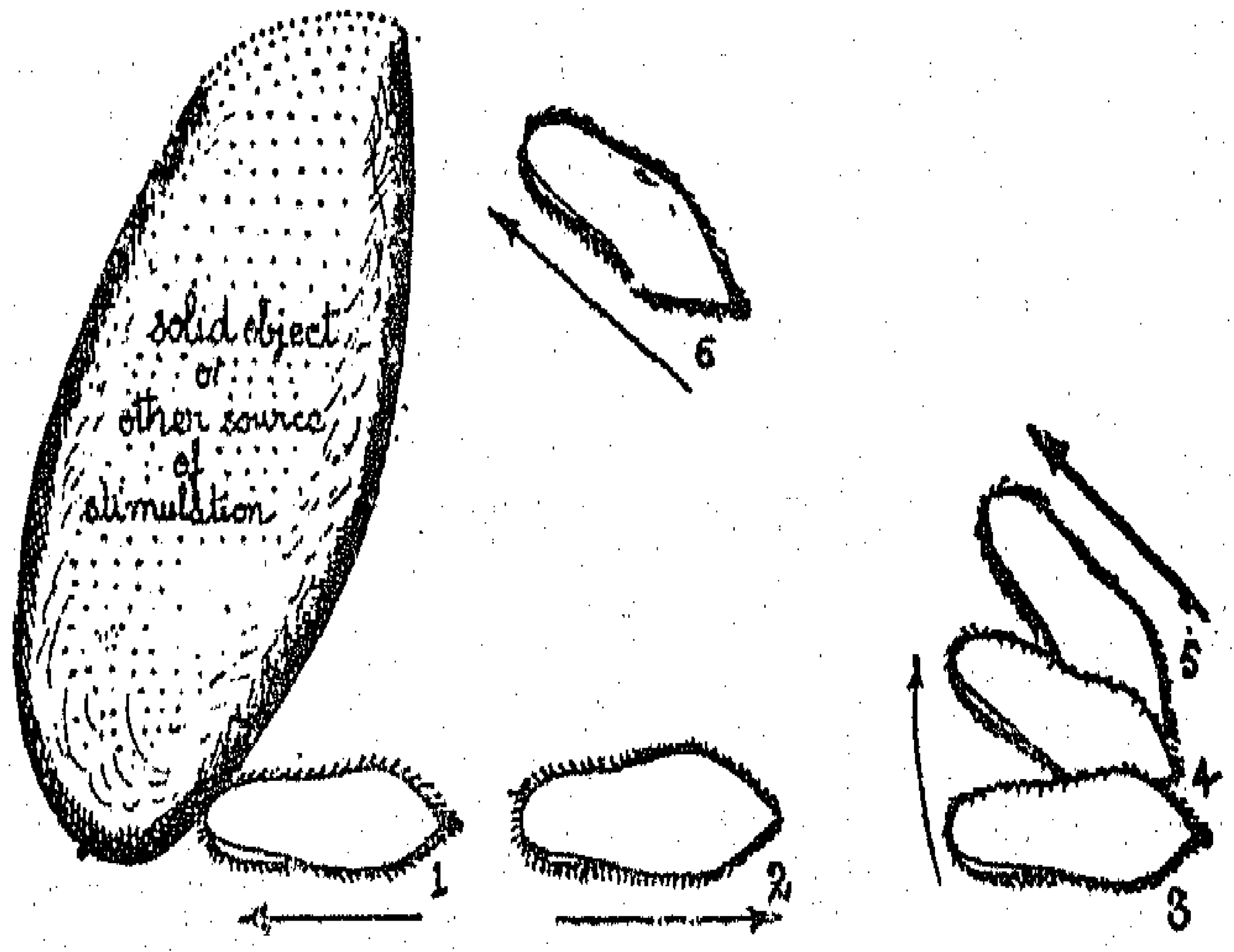
The order **Coccidia** (Sporozoa) also includes some significant pathogens; *Eimeria steidae* and *Eimeria perforans* cause a large scale mortality in young rabbits. *Eimeria zurni* causes diarrohea in cattle; *E. tenella* and *E. necatrix* cause fatal **coccidiosis** in poultry. *Isospora hominis* causes **human coccidiosis** and the man suffers from diarrhoea.

The order Microsporidia includes *Nosema bombycis* which causes the **Pebrine disease** in silk-worm and *Nosema apis* which destroys honey-bees.

19

Behaviour in Protozoa

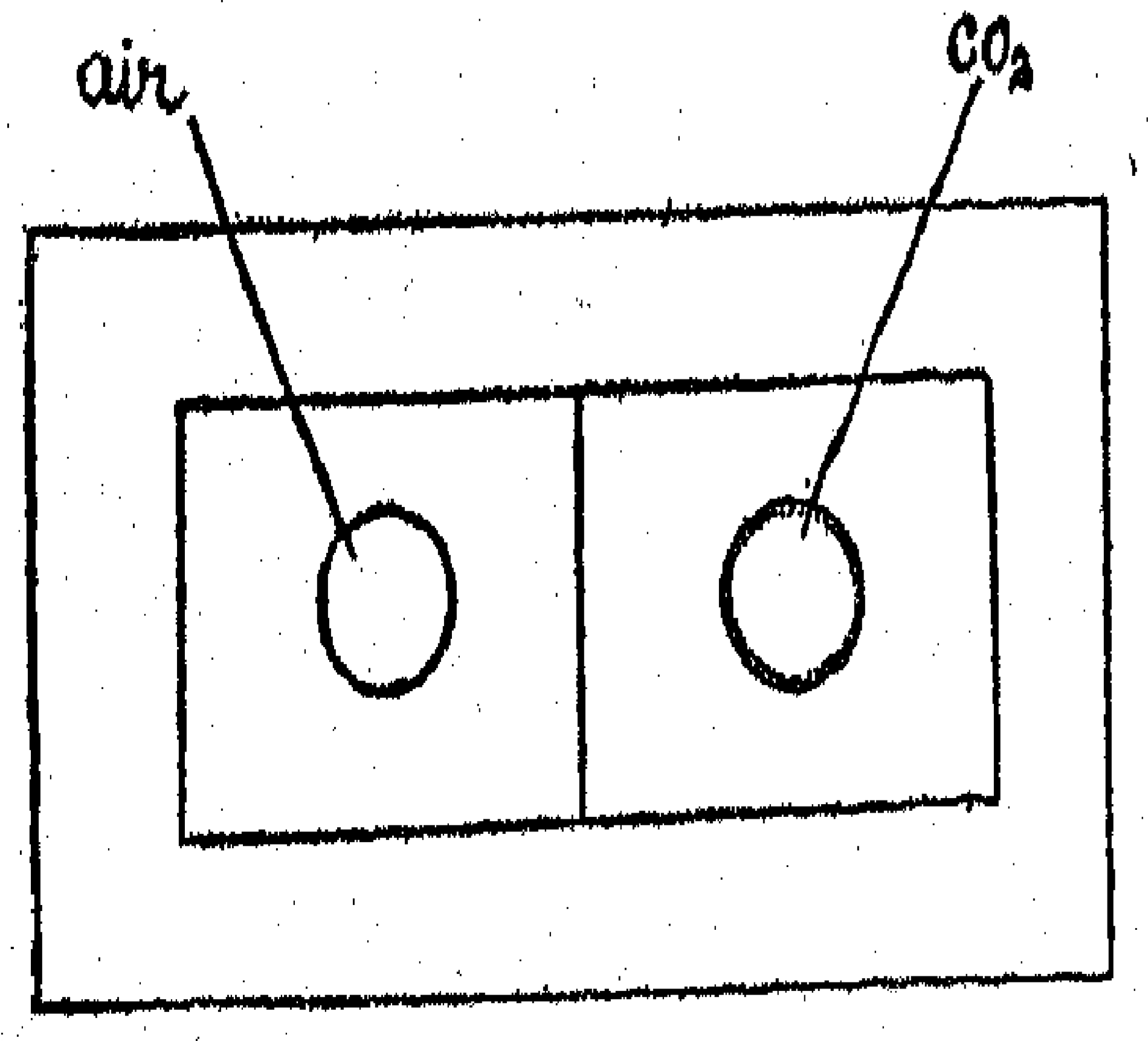
The sum total of all activities of an animal is known as *behaviour.* Behaviour includes all actions which constitute the activities of the animal as an organism. To be more precise, *behaviour* includes the activity of an organism as well as changes of activity. In other words, the *behaviour* of an organism is that part of its life which comprises action upon the outer world. Behaviour comprises activity of various kinds—mechanical, chemical etc., which may be (i) due to external stimuli or (ii) without them, e. g. the beatings of cilia are not due to any external circumstances; it is remarkable that both these kinds of activities are normally such that they are conducive to the welfare of the organism. The reactions of the Protozoa exhibit a superficial analogy to the reflexes in Metazoa.



Paramecium showing avoiding reaction; 1 to 6 represent successive positions occupied by the animal. (After Jennings)

Fig. 76

The reactions of the Protozoa are of two kinds: *kineses* in which the stimulus leads to an increase in the random movement of the animal e. g. the avoiding reaction of *Paramecium* in which it turns through an angle each time it is stimulated till finally it becomes free from the influence of stimulus; the response in this case is *random*, for, as a result of initial turns the animal stands almost equal chances of meeting or avoiding the stimulus: *Bodo,*



Paramecia surround the CO_2 bubble in preference to the air bubble.

Fig. 77.

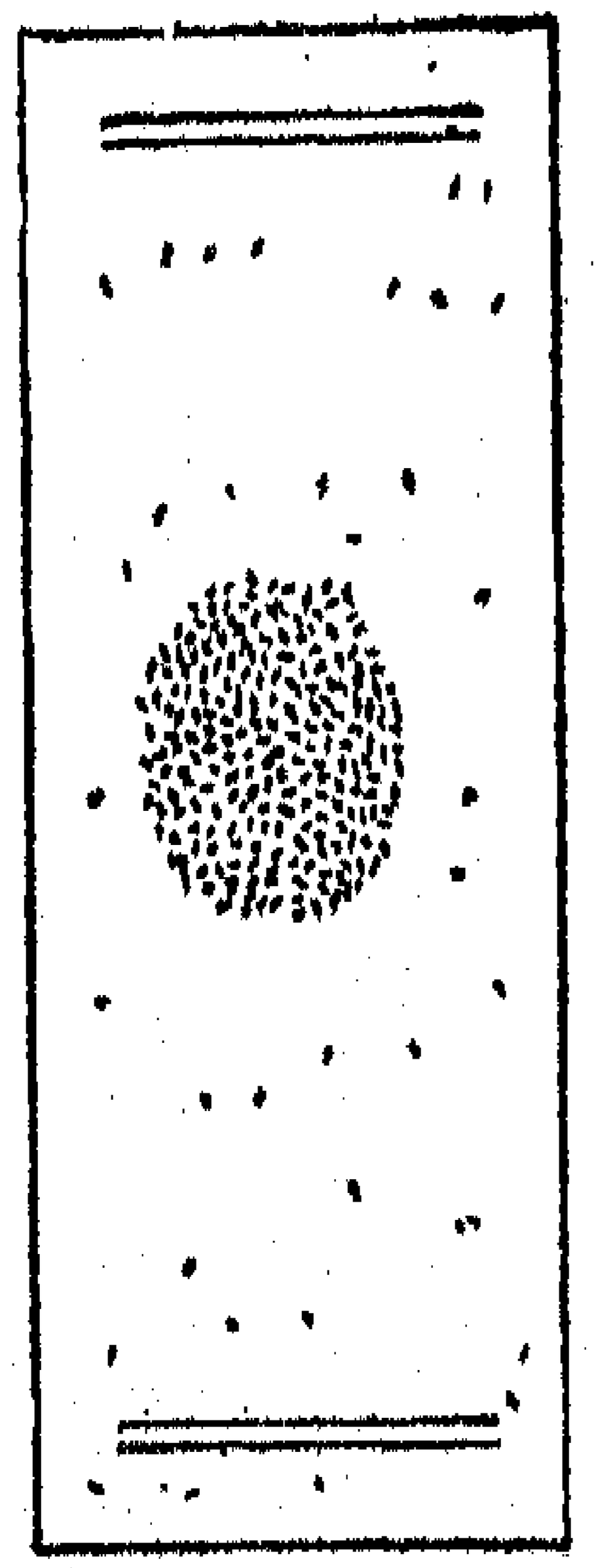


Fig. 78. Collection of Paramecia
acid shawing a positive reaction (After
in a drop of weak acetic Jennings.)

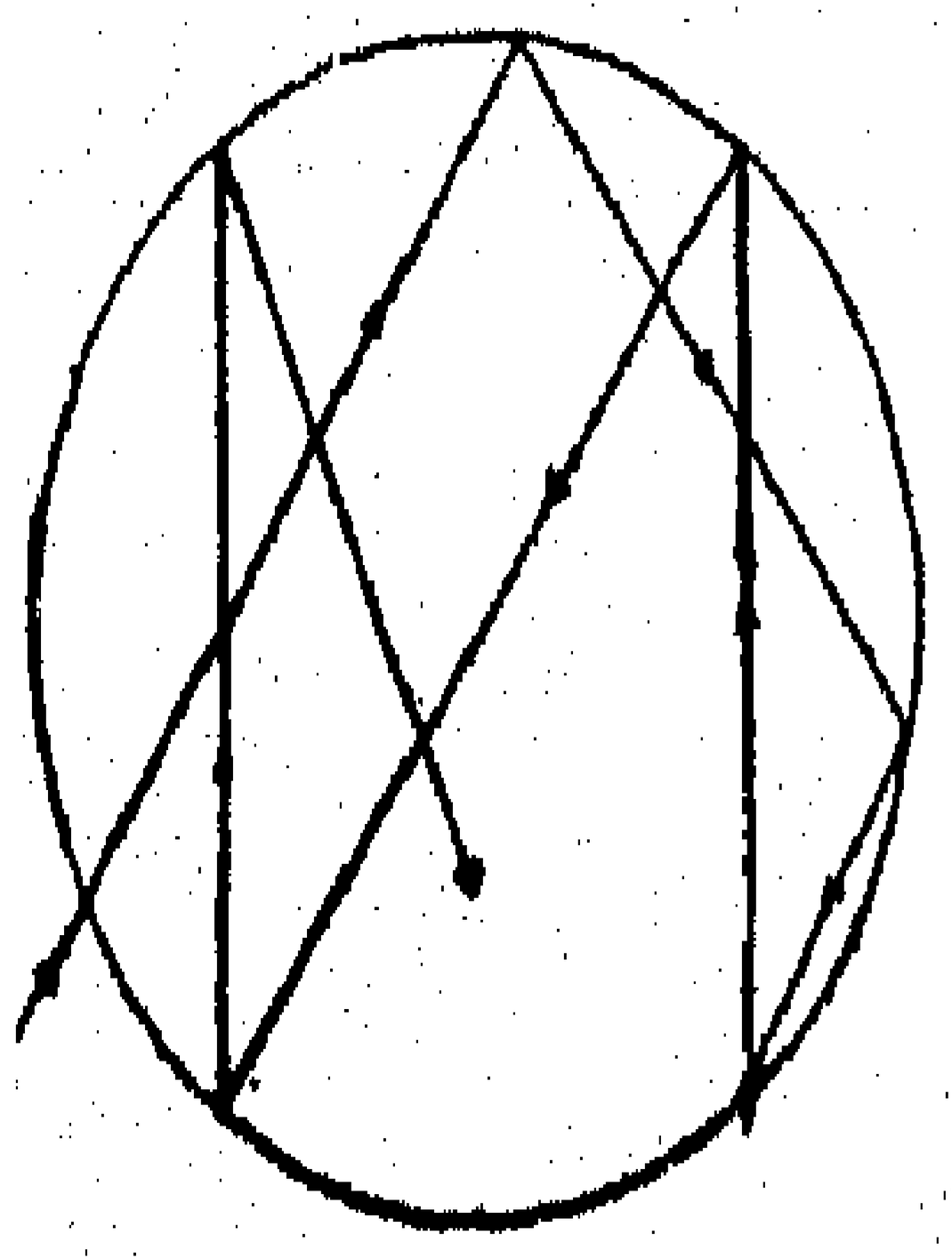
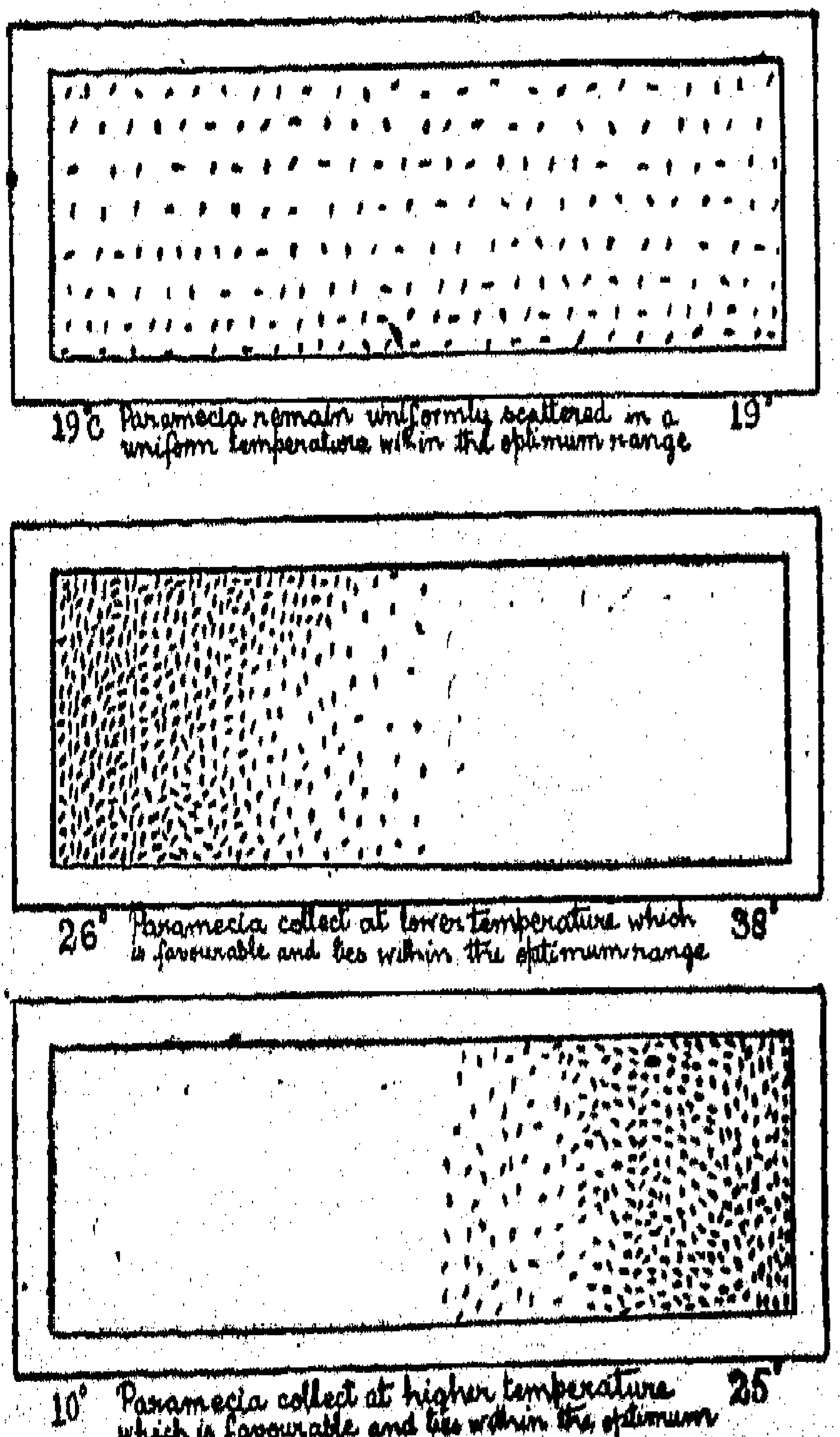


Fig. 79.
Diagram showing the manner in which Paramecium shows avoiding reaction every time it comes to the boundary of the acid drop (After Jennings).



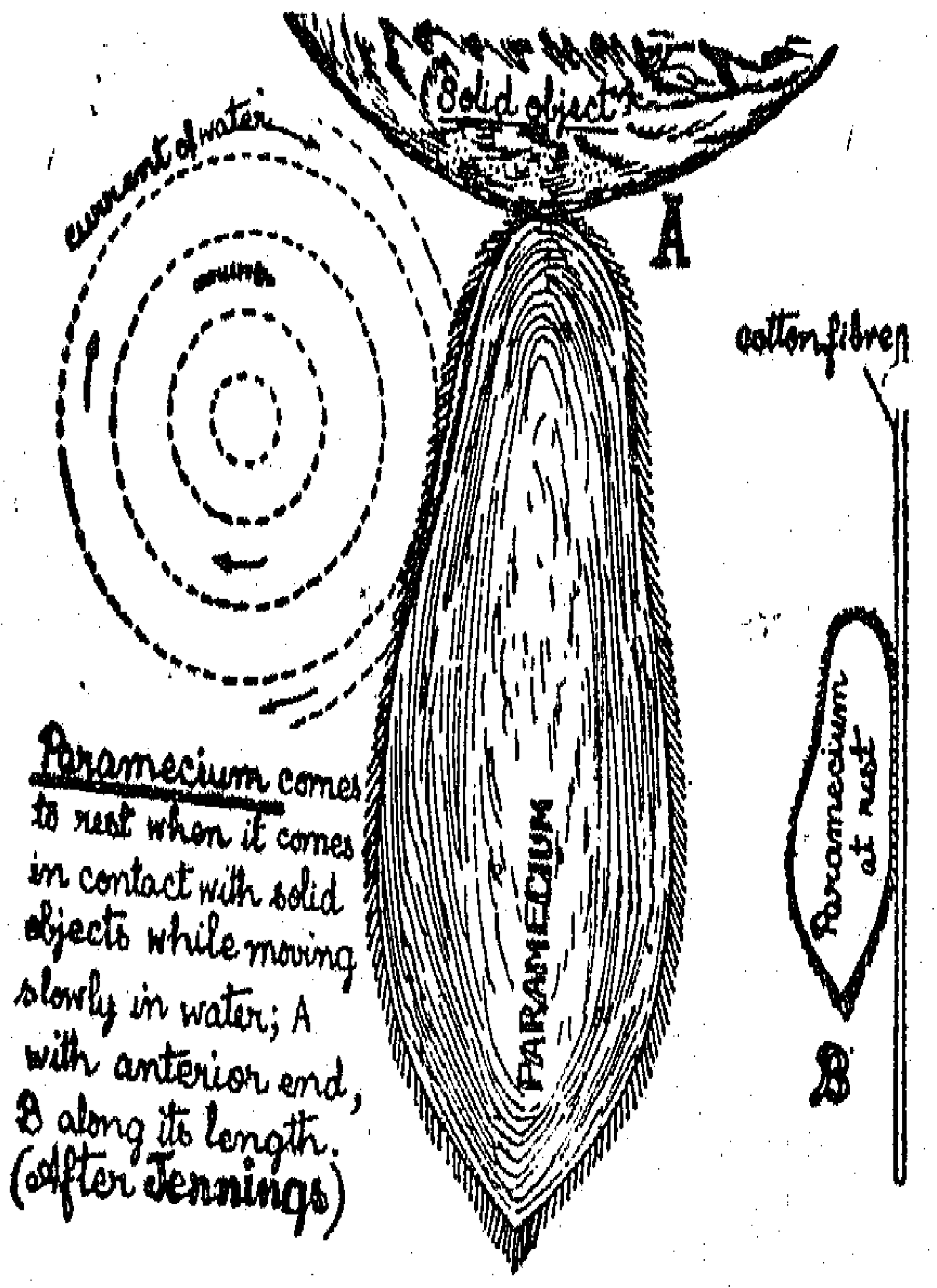
Paramecia remain uniformly scattered in a uniform temperature within the optimum range

Paramecia collect at lower temperature which is favourable and lies within the optimum range

Paramecia collect at higher temperature which is favourable and lies within the optimum range.

Fig. 80. Temperature reaction in Paramecium (After Mendelssohn).

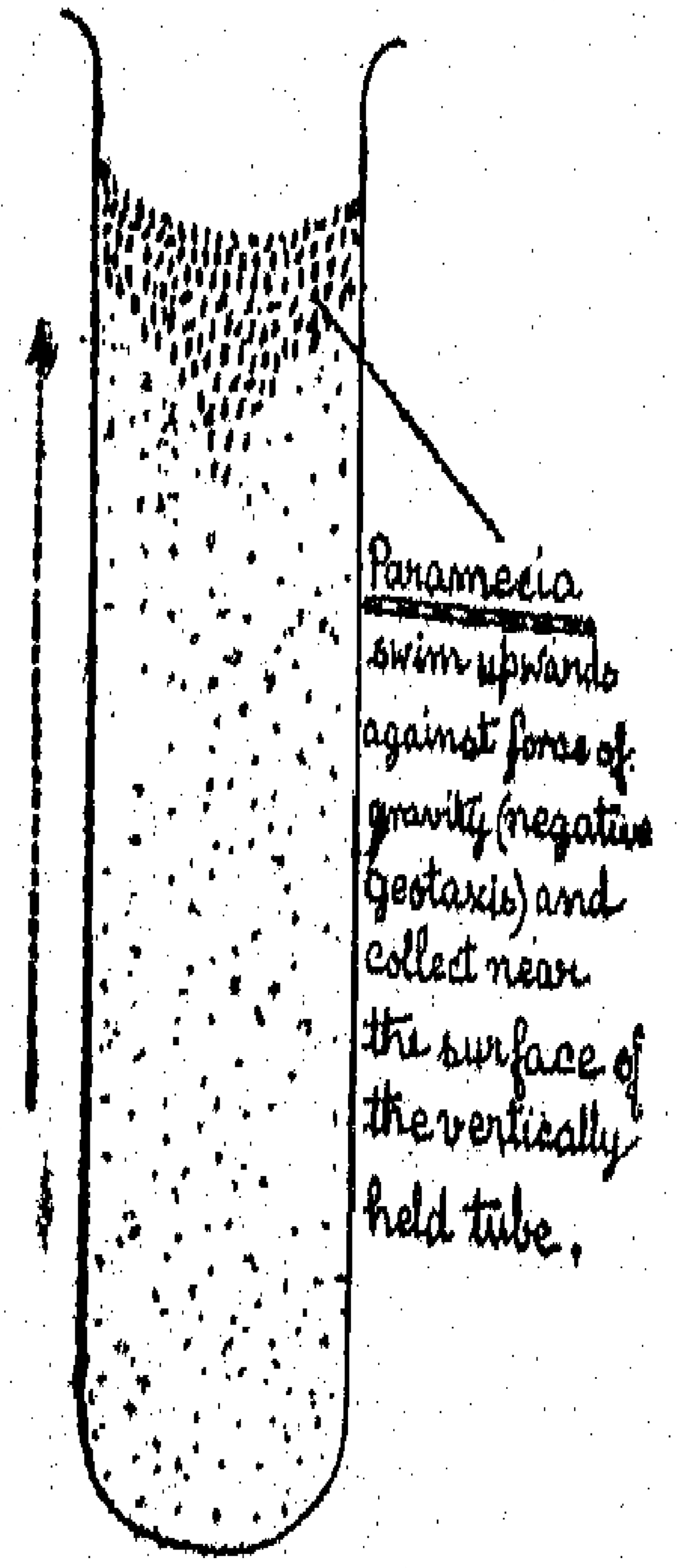
as a result of kinetic responses, under the influence of a chemical stimulus moves towards and into a favourable oxygen tension;



Paramecium comes to rest when it comes in contact with solid objects while moving slowly in water; A with anterior end, B along its length. (After Jennings)

Fig. 81.

(ii) *taxes* in which the reaction is directed to the stimulus; these reactions depend on the possession of a sense organ; e. g. in *Euglena,* the base of the flagellum is sensitive to changes in light



Paramecia swim upwards against force of gravity (negative geotaxis) and collect near the surface of the vertically held tube.

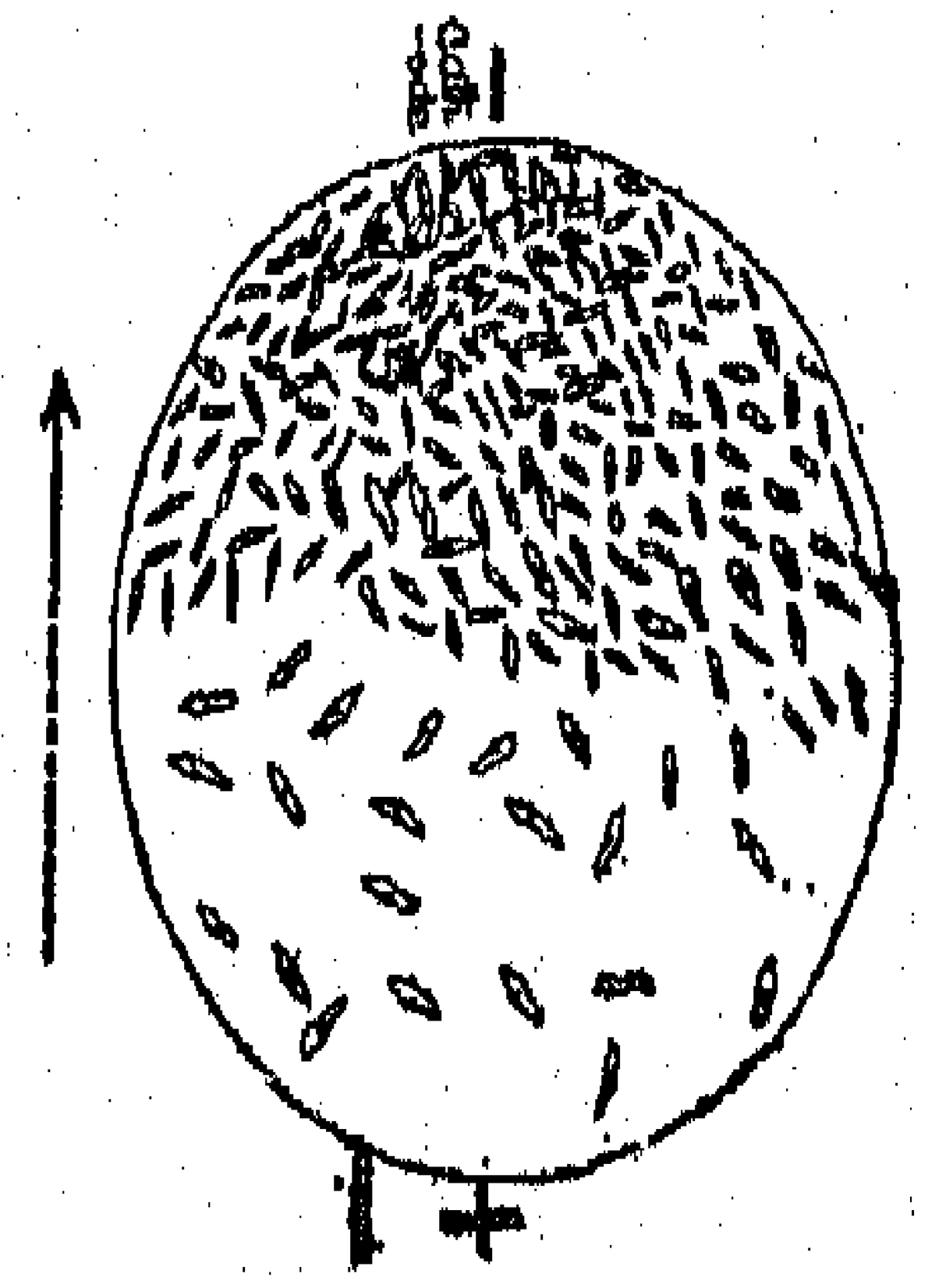
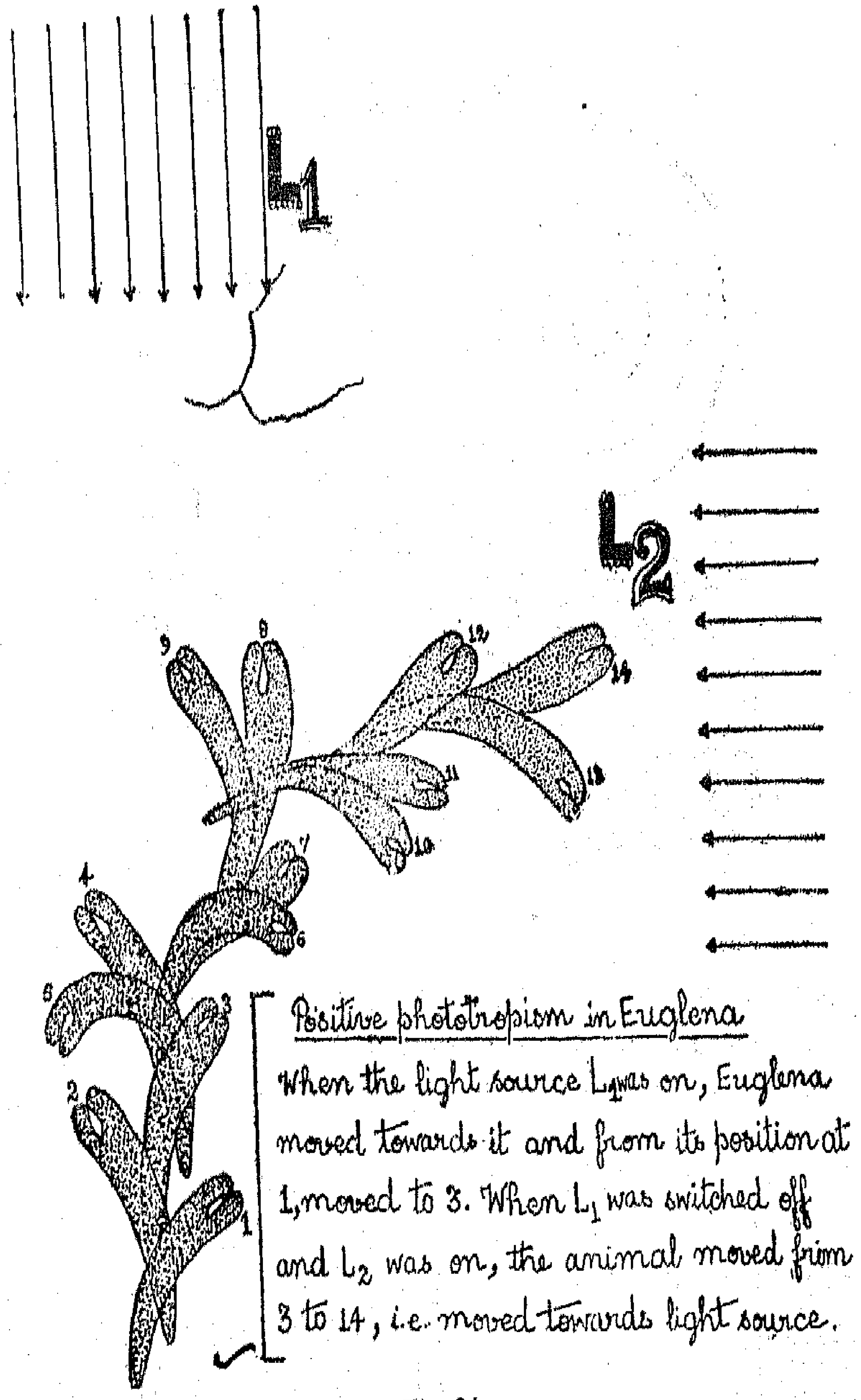


Fig. 82. Paramecia are attracted towards cathode in a weak but constant electric current (After Verworn).

Fig. 83. Paramecium showing negative geotaxis.

intensity; when *Euglena* is stimulated from one side by light, it swiftly adjusts its movements so that it is once more directed towards the light. The response occurs in relation to the position



Positive phototropism in Euglena

When the light source L_1 was on, Euglena moved towards it and from its position at 1, moved to 3. When L_1 was switched off and L_2 was on, the animal moved from 3 to 14, i.e. moved towards light source.

Fig. 84

of the stimulus and not by a simple increase in the random movement of the animal.

In case of *Amoeba*, responses to various stimuli occur due to the general property of irritability of protoplasm. Such responses, as already stated, in *Amoeba* as well as in other organisms, are beneficial to the life and security of the animal; either these responses tend to save the animal from facing the hazards of extended exposures to the harmful stimuli or they tend to bestow a positive advantage upon the organism. The protrusion of the pseudopodia to engulf a food praticle and amoeba's natural attraction towards food particles are examples of the responses immediately beneficial to the organism.

A reaction is described as **positive** if the animal moves or tends to move towards the source of stimulation; it is said to be

negative in case the animal moves away from the stimulus. A stimulus may be *internal* or *external*. Hunger is a familiar internal stimulus.

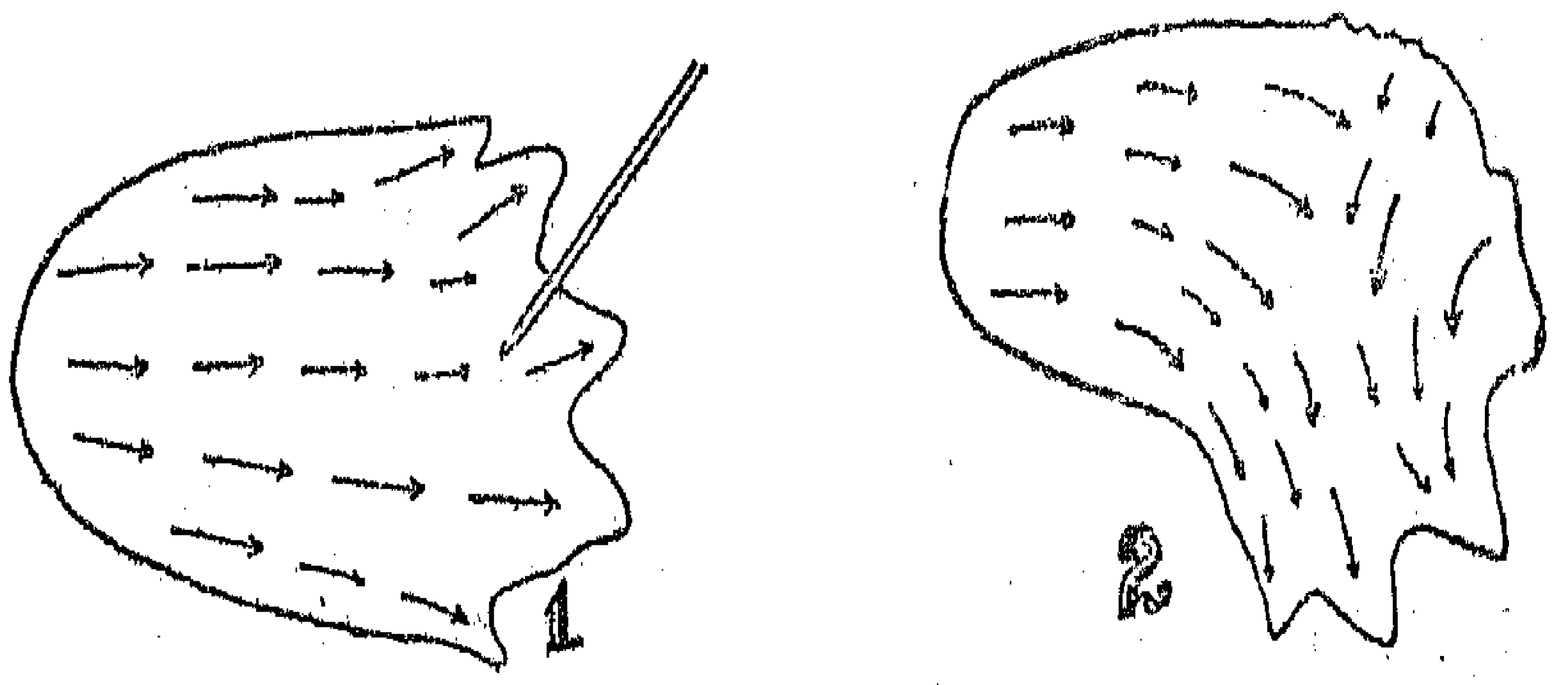
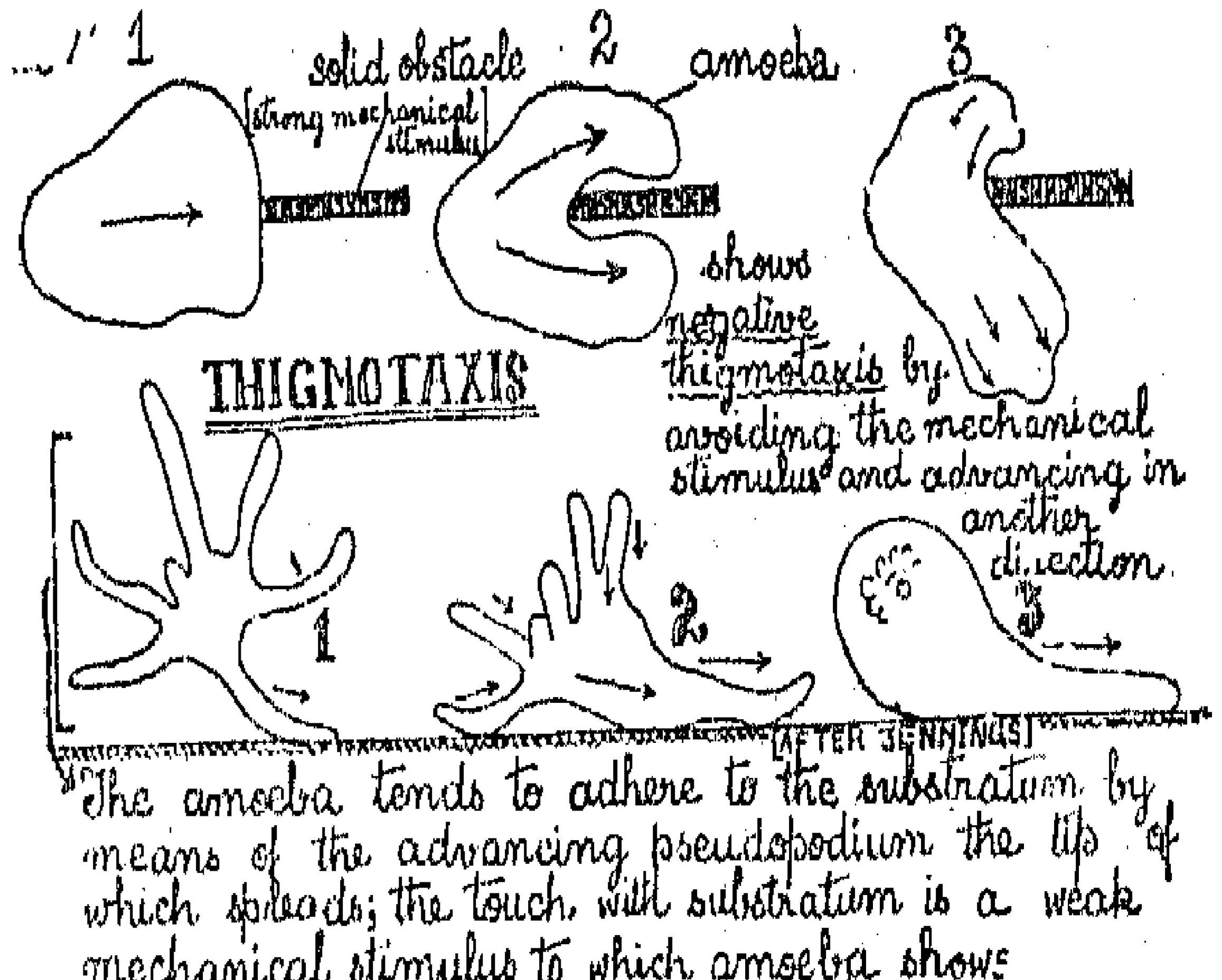


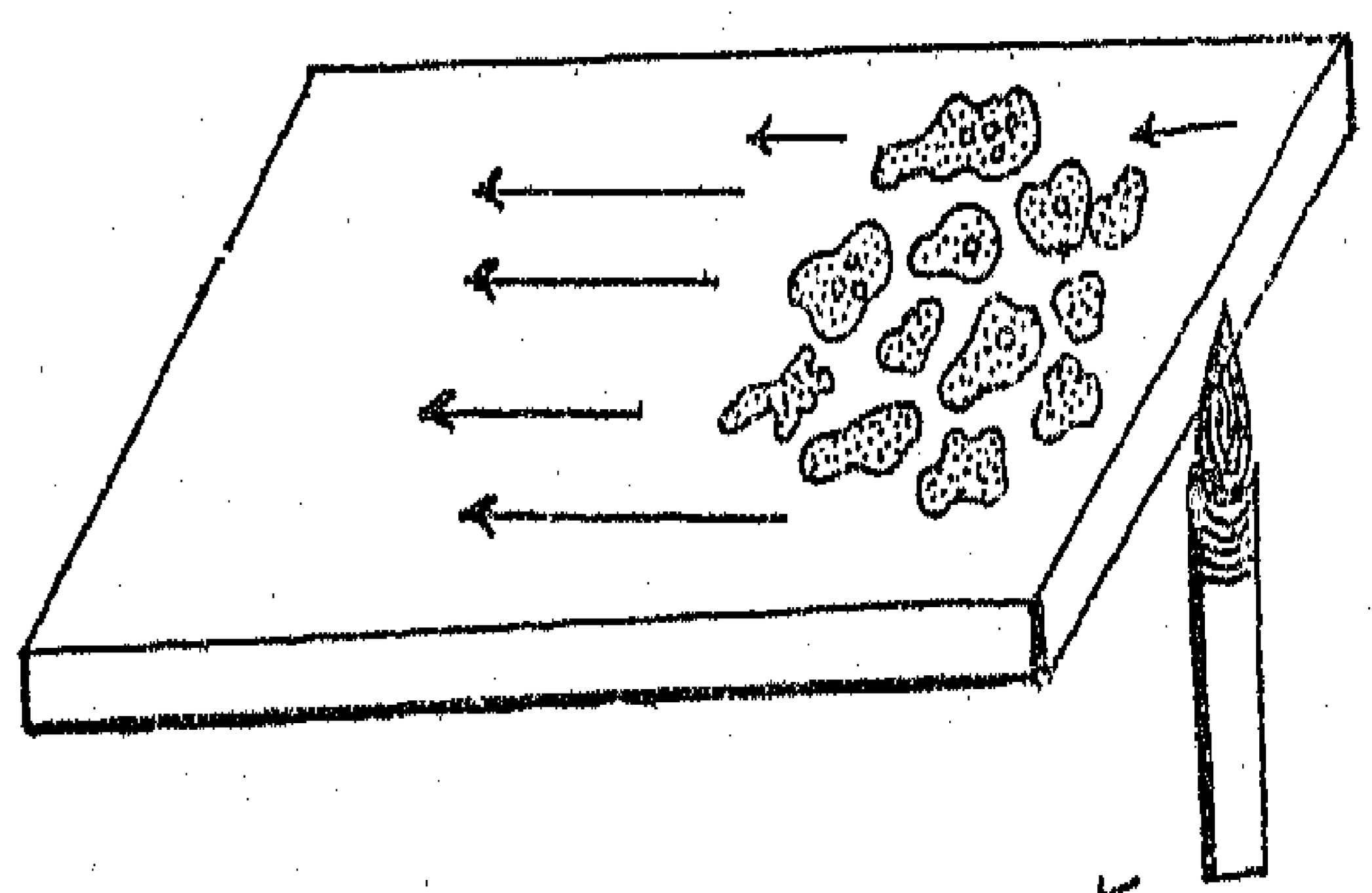
Fig. 85 and 86. Amoeba—Reaction to a strong mechanical stimulus showing negative thigmotaxis. (After Jennings).

Tropism or *taxis* are the terms used for movements or orientation of an organism in response to stimulus. **Thigmotropis** is the reaction to mechanical stimuli, such as touch, (2) **Phototroism** is the reaction to light (3) **Chemotropism** is the reaction to chemical stimuli (4) **Thermotropism** is the reaction to heat, (5) **Galvanotropism** is the reaction to electric current (6) **Geotropism** is the reaction to gravitational force and (7) **Rheotropism** is the reaction to water current.[1]


1
solid obstacle
[strong mechanical stimulus]
2
amoeba
3
shows negative thigmotaxis by avoiding the mechanical stimulus and advancing in another direction.
THIGMOTAXIS
1
2
3
[AFTER JENNINGS]

"The amoeba tends to adhere to the substratum by means of the advancing pseudopodium the tip of which spreads; the touch with substratum is a weak mechanical stimulus to which amoeba shows POSITIVE THIGMOTAXIS

Fig. 87



Experiment to show negative thermotaxis in Amoeba [Amoebae move away from the hot region]

Fig. 88

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[1] For details see pages 179 to 183, 211 to 213 and 303 to 308 of 'A text-book of Invertebrate Zoology' (1963 Edition) by **Murli Manohar Saxena**].

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Characters of the Phylum Porifera

The **Porifera** constitute a group of plant-like sessile animals profusely equipped with minute pores on their body surface (L. *porus*, a pore, *ferre*, to bear). They rank higher than the Protozoa in being *cellular*, although when considered with all other metazoa, they are the simplest and the lowest. The structure, physiology and the overall organization of the animals grouped together in the phylum Porifera are sufficiently distinct from those of all other metazoa and the mode of their embryonic development is so radically unlike any one of them that they have been aptly placed in a separate and independent animal subkingdom known as the **Parazoa**. The representatives of the Parazoa present such a high degree of uniformity with regard to their *built* and *physiology* that only one phylum namely the *Porifera* is recognized under the subkingdom—Parazoa.

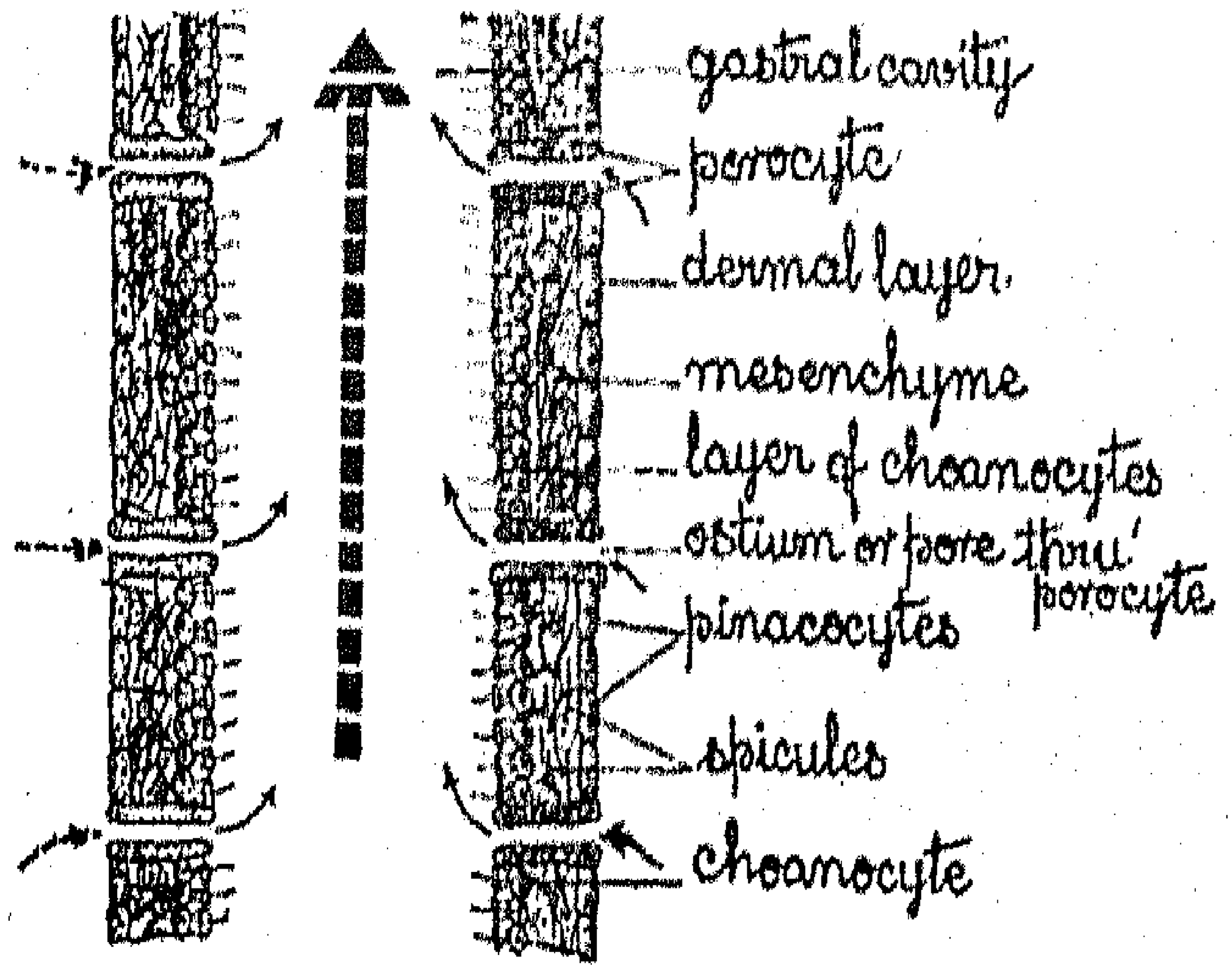

Fig. 89. Diagram showing the body-layers of a simple sponge; only a part of the body in longitudinal section has been shown. The arrows indicate the course of water-current.

The salient features of Porifera are: (i) aquatic, sessile nature in the adult stage, (ii) *cellular nature,*—loose aggregation of cells without protoplasmic connections, (iii) powers of locomotion completely absent, (iv) presence of *choanocytes* or *flagellated collared cells*, (v) no definite tissues, no specialised organs, (vi) absence of nervous system and lack of conduction and co-ordination, absence of sense-cells, (vii) skeleton consists of calcareous or siliceous spicules, or spongin fibres or both of siliceous spicules and spongin fibres, (viii) the digestion is intracellular and all are small particle feeders, (ix) great powers of regeneration are present, (x) the body consists of a very small number of types of cells, (xi) sexual reproduction occurs by ova and sperms, (xii) a free-swimming larval stage is found in development, (xiii) inversion of cell-layers occurs in development, (xiv) cleavage occurs in the embryogeny, (xv) some reproduce asexually by *gemmules* and (xvi) the *water-current* forms basis of the entire 'sponge-physiology' and is essential for its life; the water-current produced by the concerted action of thousands of choanocytes—by their flageller beatings which continue throughout life of the sponge, serves the multifarious purposes of feeding, respiration, excretion, transmission of reproductive cells and dispersal of *gemmules*: the agents of asexual reproduction found in some sponges. The water-current is therefore all-important for the life of sponge which chiefly acts as a pump, passing a current of water through its body all the time, extracting from it food and oxygen and in fact depending upon it for all exchanges between itself and the external medium which is aquatic in all cases.

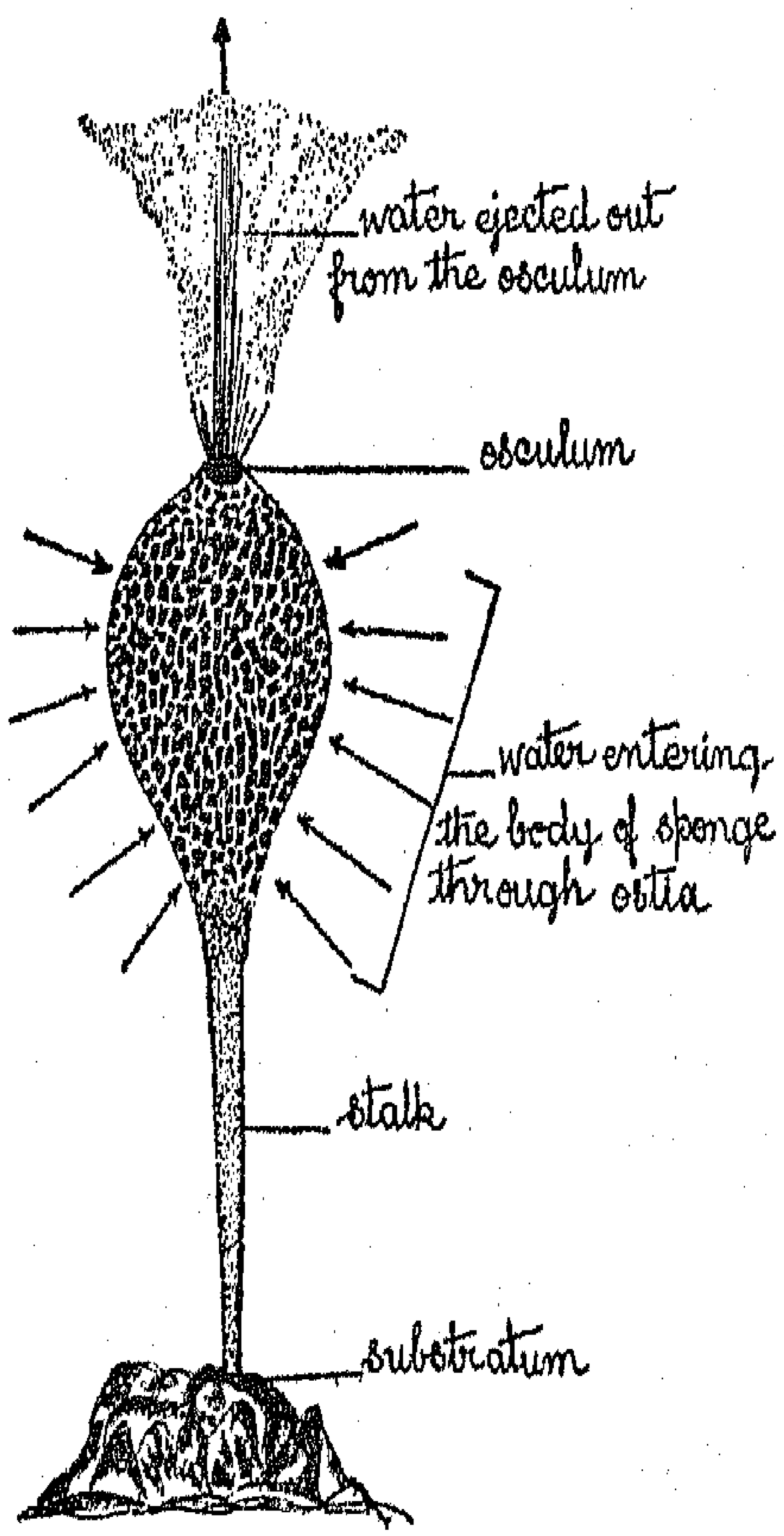
water ejected out from the osculum
osculum
water entering the body of sponge through ostia
stalk
substratum

Fig. 90. Course of water-current in a simple sponge.

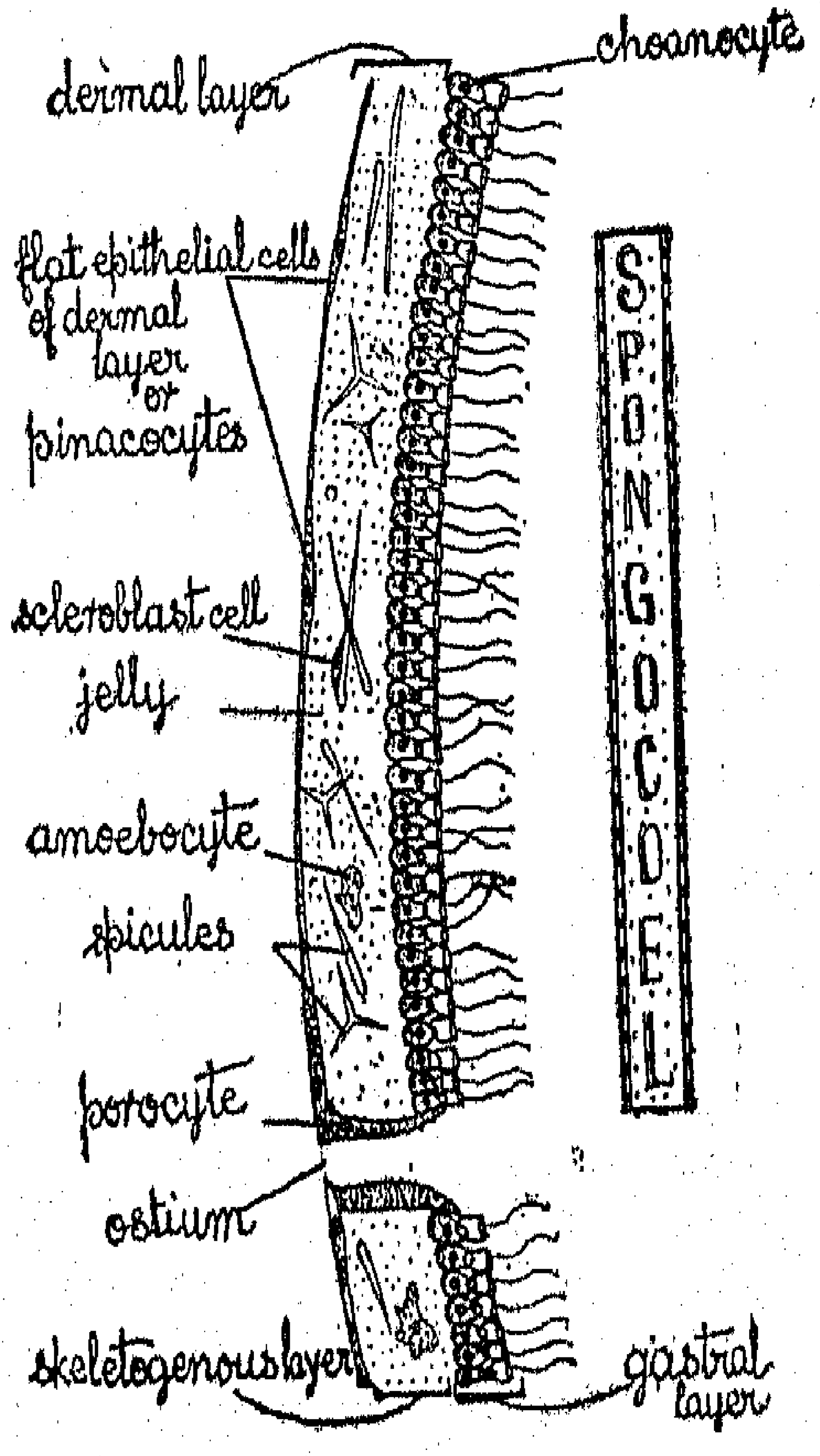

Fig. 91. Structure of body-wall of a simple sponge.

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Structure of a Simple Sponge

1. **Write notes on the following**: (*c*) *Leucosolenia.*
(B. Sc. Prel. 1954)

2. **Describe the structure of simple sponge giving suitable examples.**

Leucosolenia is a simple marine sponge found in tide mark places; the body consists of a horizontally growing stolon from which hollow tubular vertical branches are given off. Each vertical tube has a large opening known as **osculum** at its distal extremity. The surface of the vertical tube is pierced with innumerable minute pores known as **ostia** through which a current of water is always entering the interior of the vertical tubes; and hence the ostia are called *'incurrent pores'*. All the water that enters the vertical tubes through ostia escapes through their respective oscula which act as the exhalant or the *excurrent apertures*. Each vertical tube represents a single individual of *Leucosolenia* and the number of tubes connected by hollow horizontal branches represent a 'colony' of the sponge.

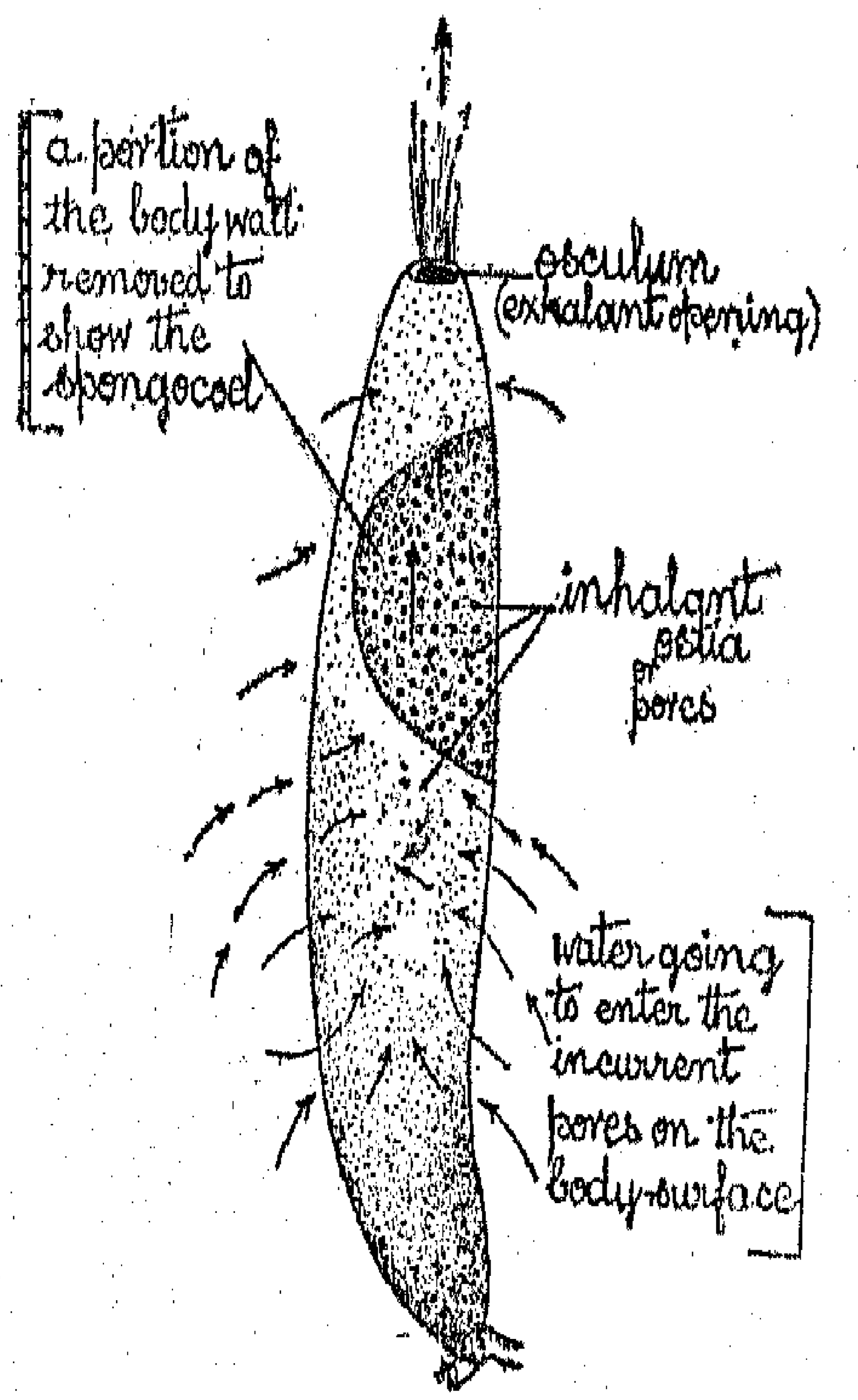
a portion of the body wall removed to show the spongocoel
osculum (exhalant opening)
inhalant ostia pores
water going to enter the incurrent pores on the body-surface

Fig. 92. Leucosolenia (A single individual).

The hollow interior of each vertical tube is known as the **spongocoel,** *paragastric cavity*, *paragaster* or the gastral cavity; the internal cavity of all the members of a colony communicates by the hollow branches running horizontally between their bases giving rise to a single, common **gastral cavity.** Since the water escapes through the osculum it discharges a function completely different from that of the mouth; in fact, the osculum does not represent the mouth opening. The osculum is surrounded by a number of projecting rod like calcareous spicles which form the **oscular fringe.**

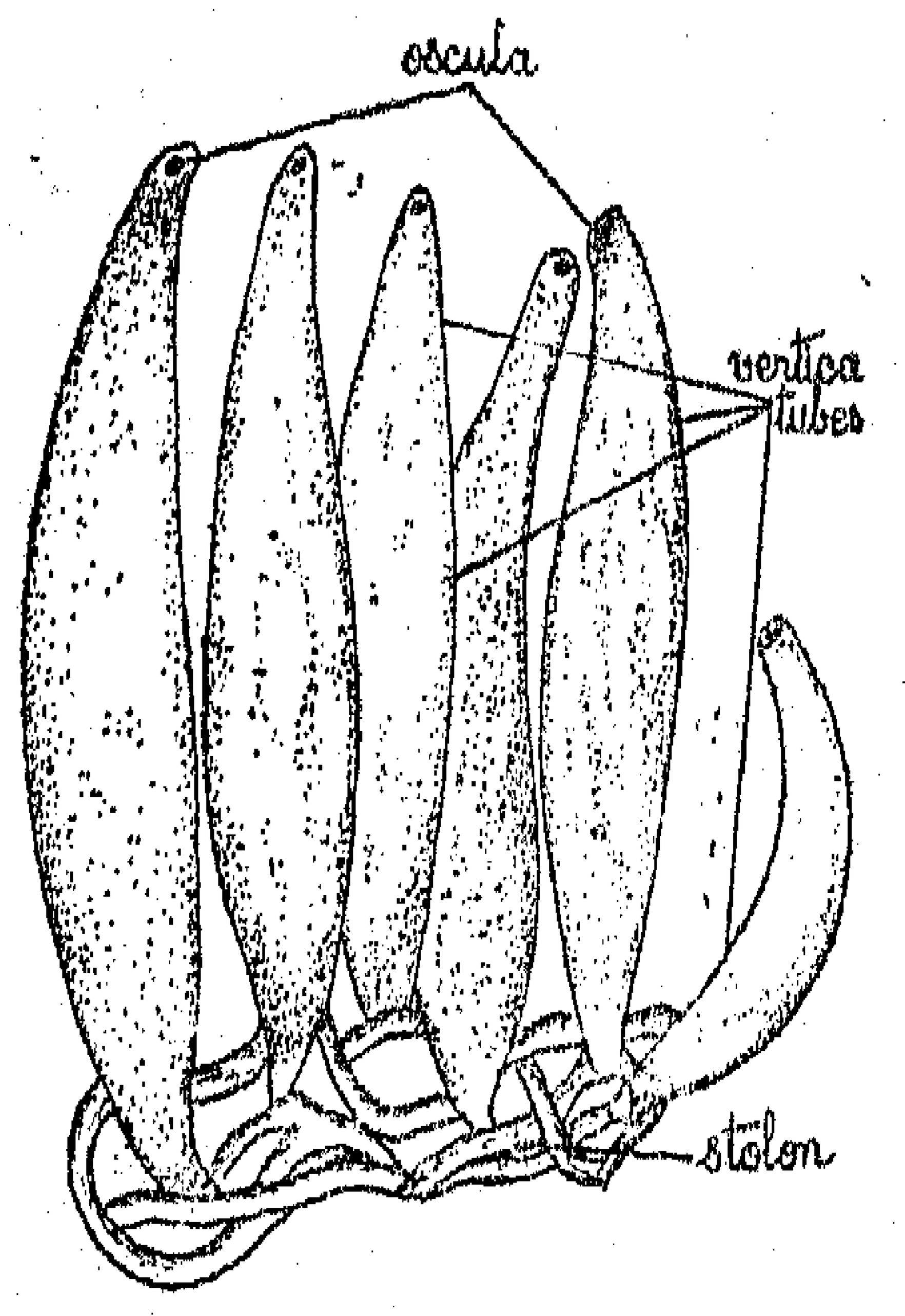

Fig. 93. Diagram illustrating the structure of Leucosolenia.

Each incurrent pore of the body-surface or ostium is *intracellular* running through a single cell known as the **porocyte;** the pore is completely inside a single cell and establishes communication between the external world and the spongocoel, the pore naturally extends through the wall of the sponge. During life, the sponge is capable of drawing a steady and continuous current of water into its body through the inhalant pores and at the same time water is constantly flowing out through the osculum.

The body-wall is composed of an (1) outer **dermal layer** and an (2) inner **gastral layer.** The dermal layer is composed of two distinct parts (i) an outer layer of flattened epithelial cells known as the *pinacocytes* and (ii) an inner *skeletogenous layer* which, as the name indicates, gives support to the body by means of the skeletal elements contained in itself; the skeletogenous layer contains a jelly embedded in which lie scattered cells of various kinds; certain cells secrete spicules of calcium carbonate and these cells have been termed as the *'scleroblasts'* (See figure no. 91); the jelly (or the gelatinous layer) contains in addition a number of *amoeboid-wandering cells* or *amoebocytes*; of these, some amoebocytes give rise to reproductive cells while certain others are concerned in the 'transport' of nourishment and excreta from one place to the other inside the body of the sponge. Digestion like all sponges, is intracellular and hence the transport of food by these cells acting as 'carriers of food supplies' from the place of availability to the place of need has become an important function.

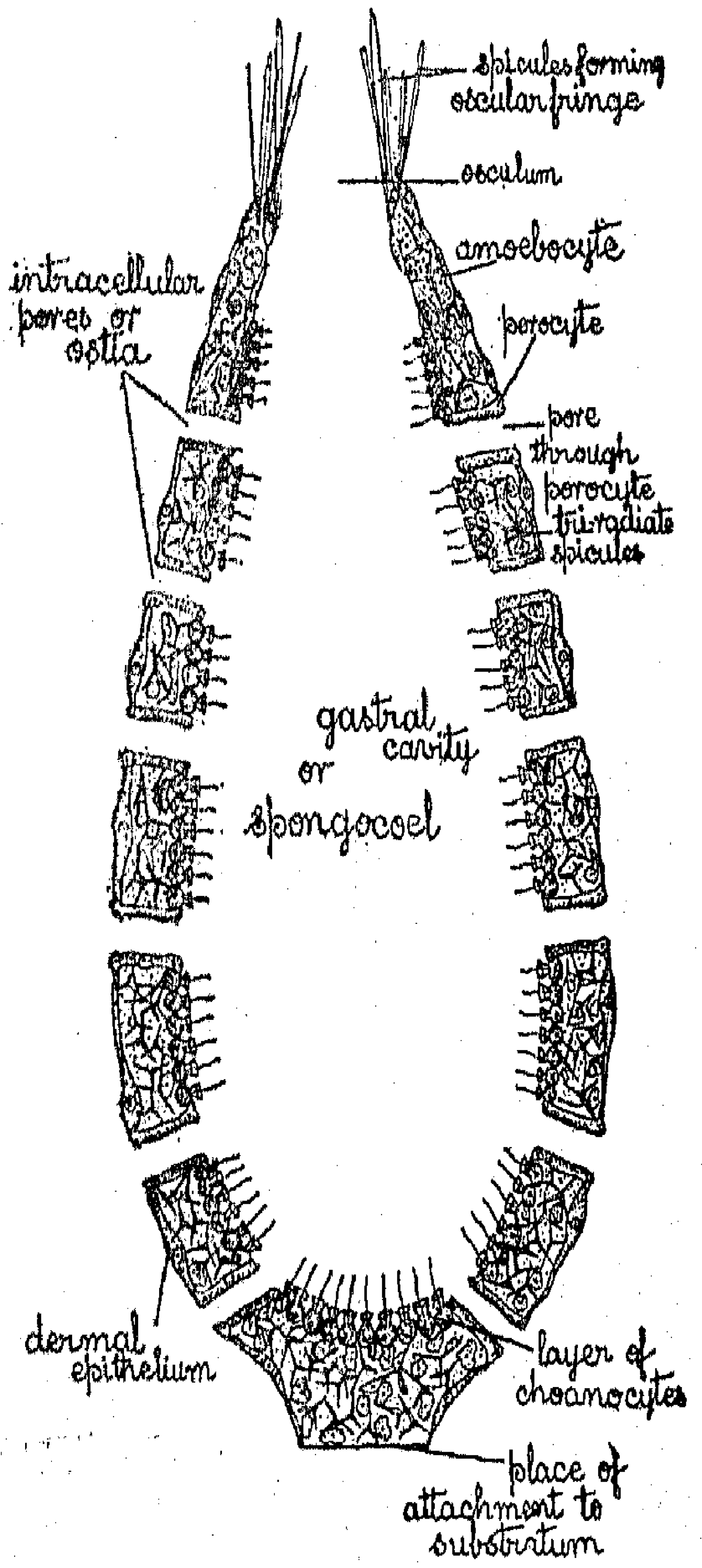

Fig. 94. Diagram to show the structure of a simple sponge (Diagrammatic longitudinal section).

There are absolutely no sense cells or nerve cells in the sponge body. The spicules in a simple sponge are mostly triradiate; these are three rayed minute microscopic calcareous elements.

The *amoeboid cells* from which the reproductive cells are formed are called *archaeocytes*; the whole of the middle layer consisting of the jelly, spicules and the scattered cells is often called the **mesogloea**; it is same as the skeletogenous layer.

The inner of the two constituent layers of the body, the *gastral layer* is composed of flagellated collar-cells known as *choanocytes*. The choanocytes line the whole of the paragastric cavity, a characteristic common to all simple sponges e. g. *Leucosolenia*, *Clathrina*; these represent the lowest grade of sponge-organization commonly referred to as the **ascon grade**. The flagella of choanocytes keep beating constantly and create a water-current that enters through the ostia and leaves through the osculum. The food particles in the passing water are thrown within the collars of the choanocytes and get stuck to them. The food particles are then ingested by the collar cells. It is from the collar cells that the wandering amoebocytes secure nutriment and carry them to the needy places. The choanocytes are concerned in feeding as well as in the production of the water-current.

The dermal layer and the gastral layer of sponges are not homologous to the ectoderm and the endoderm of metazoa.

On the osculum, a thin membrane is found which has minute holes and which forms a sieve like structure. The cells of the dermal layer round the osculum are slightly contractile and as a result the osculum can be narrowed or closed. The osculum is surrounded by a fringe of rod like linear spicules forming the oscular fringe. In case of *Leucosolenia*, the body-surface shows polygonal elevations.

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22

Structure and Physiology of Sycon

1. **Give an account of the microscopic structures of *Sycon* and indicate the chief characters that distinguish Porifera from Coelenterata.** (L. U. 1953)

2. **Give an account of the various histological elements found in Sycon and discuss their origin from the cells of the amphiblastula.** (L. U. 1951)

Sycon is a grey or light brown, marine calcareous sponge with large choanocytes found attached to the surface of a rock or any other solid substratum submerged in the sea-water. The entire sponge is a cluster of vases or hollow branching cylinders connected together at their bases; each vase is 1 to 3 inches long and possesses a terminal *osculum* which is an exhalant aperture always expelling fluid through it and never in taking anything. *Osculum* is neither a mouth opening nor a cloacal opening; it is peculiar to sponges.

On the body-surface are found innumerable polygonal elevations demarcated by linear depressions running parallel to the sides

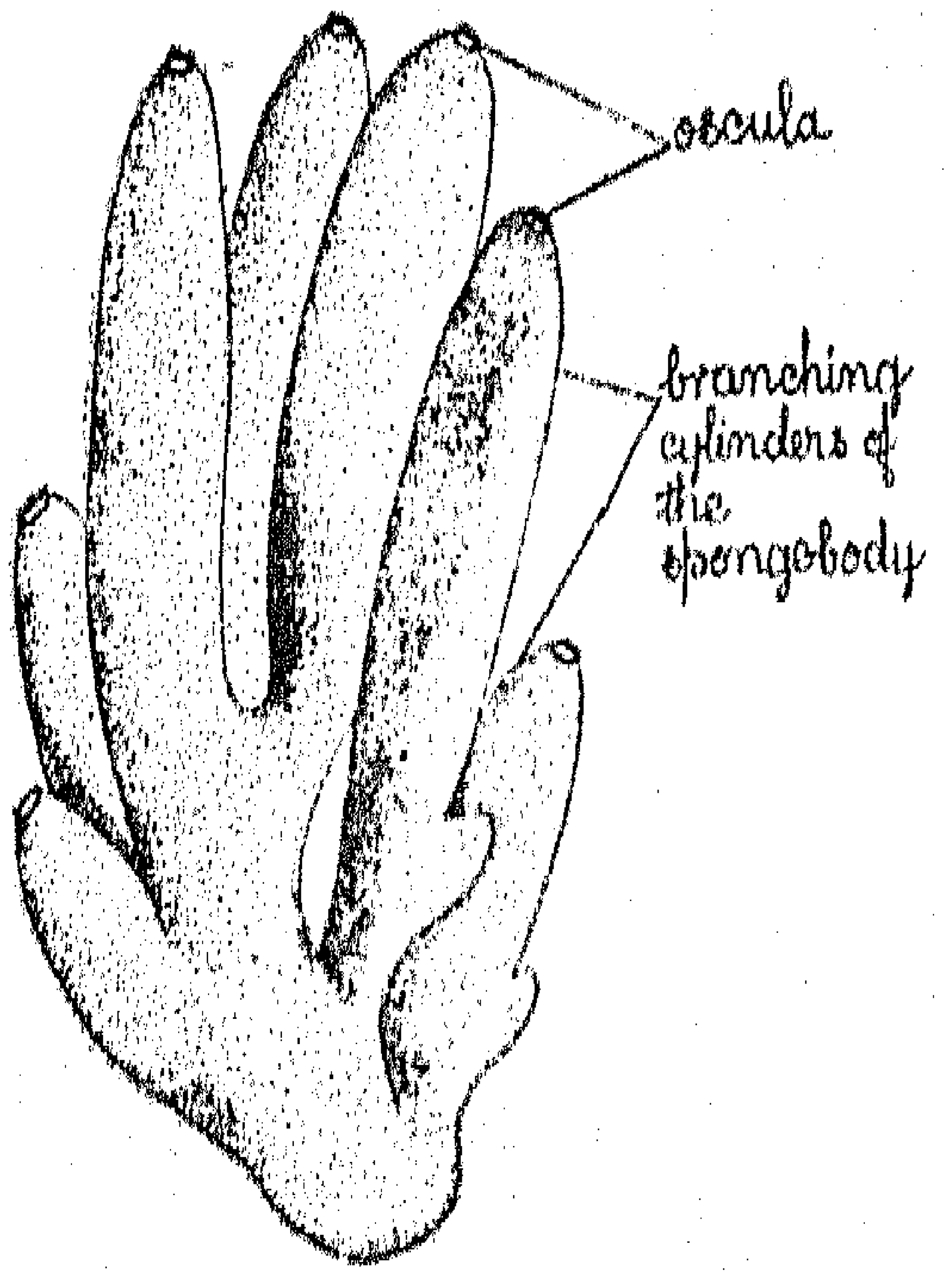

oscula
branching cylinders of the spongobody

Fig. 95. Sycon.

of the polygons which can be made out only under microscope. In the depressions are found numerous minute incurrent pores or *ostia* through which water constantly enters into the living sponge.

The bodywall of *Sycon* is thicker and structurally more complicated than that of *Leucosolenia.* The bodywall of *Sycon* is traversed by two sets of canals: (i) the *incurrent canals* and (ii) the **radial,** or **flagellated canals** to which, the choanocytes are restricted; the two sets of canals alternate and run side by side in the bodywall. In between the canals is found the sponge tissue. Adjacent incurrent and the flagellated canals communicate with each other by means of small apertures known as *prosopyles.* The prosopyles of *Sycon* correspond to the *ostia* of *Leucosolenia* and are intracellular.

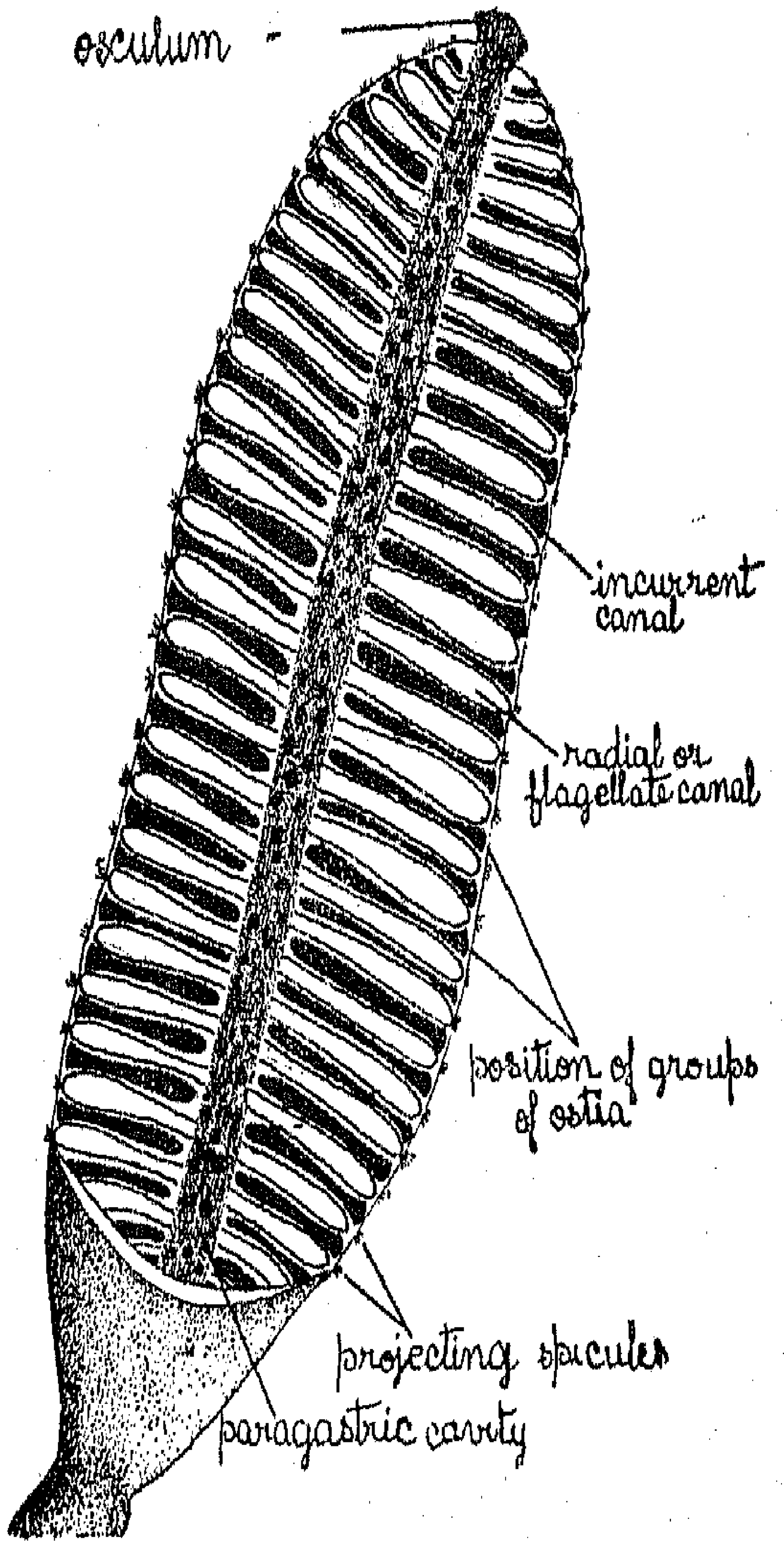


Fig 96. Sycon's cylindrical body cut longitudinally through the axis to show the paragaster and the two sets of canals. (Diagrammatic).

The *incurrent canals* are closed at their inner sides towards the paragaster and are open towards their outersides towards the exterior.

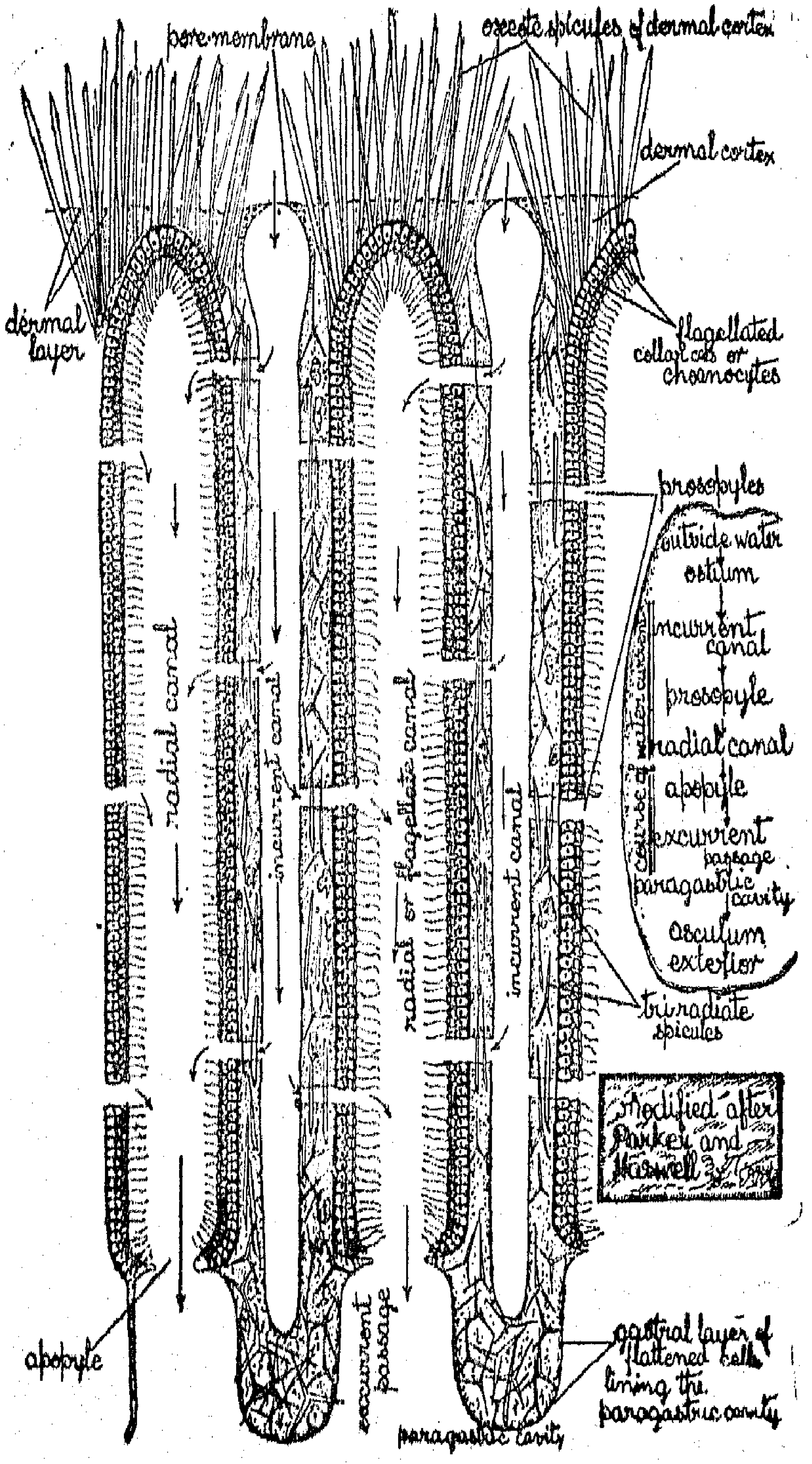


Fig. 97. Transverse section through the body wall of Sycon, parallel to the length of canals (Semi diagrammatic).

At its outer extremity each incurrent canal becomes dilated and these dilations are covered over externally by a thin membrane known as the *pore-membrane* which bears a few minute openings known as **ostia**; these pores serve as incurrent or inhalant openings for the sponge and through them water enters into the body. The incurrent canals are lined by epidermal cells or the *pinacocytes* and are narrower than the radial canals.

The distal ends of the radial canals end blindly and lie below the 'polygonal elevations' on the body surface. Towards its inner side each *radial* (or flagellated) canal narrows gradually till it is reduced to a large aperture (known as *apopyle* which leads into the *excurrent canal* which is lined by the flattened cells (*pinacocytes*) and which opens into the paragaster by a wide *gastric ostium*. The apopyle can be diminished or enlarged due to the surrounding contractile cells and fibres.

The course of water-current in *Sycon* is from the outside→ the incurrent ostia on the pore membrane→the incurrent canal→ the prosopyles→the flagellated (radial) canal→the apopyle→ the excurrent canal→the gastric ostium→the paragaster→the osculum→to the exterior.

[In case of the simple ascon sponges, the paragaster is lined by choanocytes; in *Sycon*, on the other hand, the paragaster or the spongocoel is lined by the flat epithelial cells like those which form a covering layer on the body surface. The restriction of choanocytes to one set of specialised canals traversing the body wall in case of *Sycon* and the absence of choanocytes from the general lining of the paragaster marks a fundamental difference from all simple ascon sponges. In a simple sponge, the *external ostia* lead into the paragaster directly, their inner apertures are placed in direct opposition to themselves. In case of *Sycon*, on the other hand, the ostia do not directly lead into the paragaster or the internal cavity of the sponge; in *Sycon*, the water entering through the ostia has to pass through the canals described above prior to its finally reaching the central paragaster. The 'organization grade' of *Sycon* is a step higher than that of *Leucosolenia* and is termed as the '*Sycon grade*' which comes next to the *ascon grade* in the ascending series of complexity in sponges].

If a narrow seeker is admitted through the osculum it passes into the paragastric cavity which runs axially into the vase. The paragastric cavities of a group of seven or eight cylinders intercommunicate freely, because the various cylinders are joined at their bases.

Each *choanocyte* is a columnar cell with an apical nucleus and one or more vacuoles. These columnar cells are arranged side by side in a single line to form the lining of the flagellate chamber. Each choanocyte has on its apical side a collar-like transparent protoplasmic upgrowth from the centre of which a single long flagellum emerges out.

Between the external covering layer of the body wall which is made up of the *pinacocytes* and the distal ends of the incurrent and the radial canals is a thick layer of *mesenchyme* in which along with other mesogloeal elements, calcareous spicules are found in plenty; this layer of mesenchyme lying just outer to the blind ends of the flagellate chambers is known as the *dermal cortex*. The *layer* of *mesenchyme* with the imbedded *tri-radiate* and *tetra-radiate* spicules, lying at the inner side of the canals and looking towards the paragaster is known as the *gastral cortex*.

The entire *intermediate layer* made up of calcareous spicules and a gelatinous substance consisting of jelly and different kinds of cells is known as the **mesogloea** or the **skeletogenous layer** for it contains the supporting skeletal elements responsible for the maintenance of the body-shape.

The *spicules* of calcium carbonate which form the skeleton of Sycon are of four kinds: (i) *monaxons*, (simple needle shaped) (ii) *tri-radiate* (iii) *tetra-radiate* and (iv) T-shaped spicules; the tri-radiate spicules outnumber all others. The dermal cortex has plenty of oxeote spicules (spear-like or club-shaped) while the tetra-radiate spicules are found in the gastral cortex. The T-shaped spicules are rare. The spicules are secreted by some of the amoebocytes which are called **'scleroblast cells'**.

Different kinds of cells in the body of Scyon:

Sycon's body has the following kinds of cells:

- A. Dermal layer
  - (a) *flat epithelial cells* < (i) *pinacocytes*, (ii) *myocytes*
  - (b) *porocytes*
- B. Gastral layer
  - (c) Gastral epithelium — *choanocytes* or collared flagellated cells.
- C. Mesogloea
  - (d) amoebocytes: *collencytes*, *chromocytes*, *thesocytes*.
  - (e) scleroblasts; calcoblasts — modified amoebocytes.
  - (f) archaeocytes — modified amoebocytes.

The *pinacocytes*, *myocytes*, *porocytes* and *choanocytes* have already been described. The (d) *amoebocytes* (amoeboid cells) are free-wandering cells in mesogloea and are of three kinds: *collencytes* are small connective tissue cells with thin radiating pseudopodial processes; *chromocytes* have lobose pseudopodia and possess pigment granules and *thesocytes* have plenty of food granules; thesocytes are also called *phagocytes*. The amoebocytes are all amoeba-like and serve for the transport of nutrient and excretory materials; (e) *scleroblast cells* secrete the skeleton of sponge; (f) *archaeocytes* are cells with blunt pseudopodia, large nucleus, a conspicuous nucleolus, granular cytoplasm, mitochondria and Golgi bodies. The archaeocytes play an important role in the processes of reproduction and regeneration [Sycon like other sponges possesses a remarkable power of regeneration, the capability to recover the parts of body lost or damaged.] The archaeocytes give rise to sex-cells.

Sycon completely lacks nervous system and receptor organs. Each cell acts as an independent receptor as well as an effector; specialised sense cells are not set apart and no neurones are found.

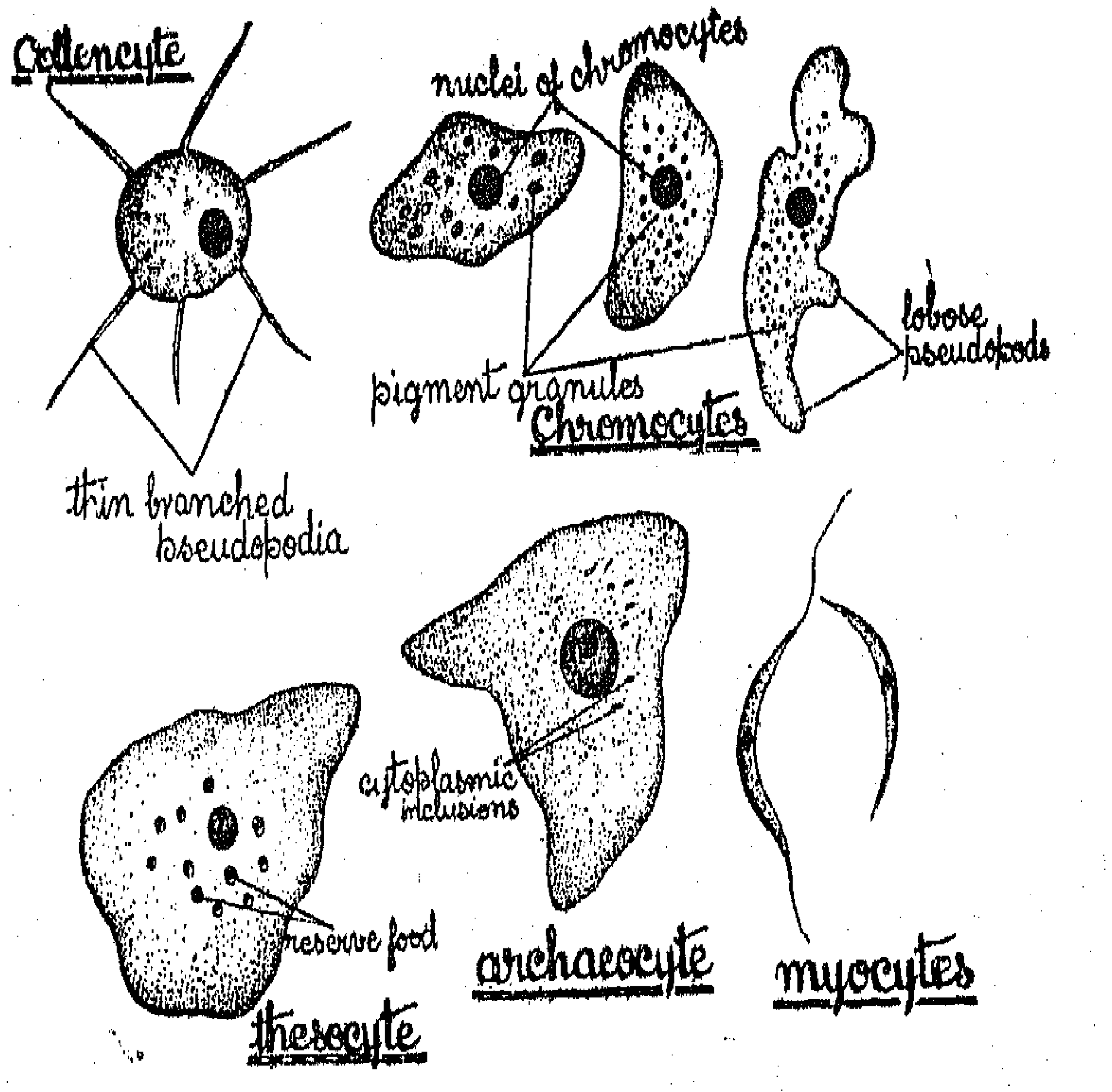


Fig. 98. Different kinds of cells in the mesogloea.

PHYSIOLOGY

Throughout life, due to ceaseless flagellar activity of the *choanocytes*, a **current of water** laden with food-particles and oxygen (and hence, the feeding and respiratory current), constantly flows through the incurrent ostia into the body of the sponge. The water thus entered leaves through the osculum. Upon this **current of water** depend the very life and maintenance of the sponge: it is the sole agency of nutrition, respiration, excretion as well as reproduction. The water-current carries with it minute organisms which serve as food for the sponge and which are availed by the collar-cells which 'hand over' the digested food to the amoebocytes which transport the nutriment to the needy cells of the sponge-body. The sponge derives all its nutrition from the water-current passing through it and hence it is known as the feeding current. The continuously passing water current also serves for the living sponge as a *flush system* for washing away the sewage being constantly produced by the organism. Excretory material is passed into the current by the collar cells. The current also provides oxygen for respiration. The water which is ejected out from the osculum once does not re-enter the body due to the relative position of ostia and the osculum. The **water current** is indispensable for the life of sponge, it is the sole pivot round which its entire physiology, routine and cycle of life revolve; a bottle neck to its free-flow would be a blow to its breath, its belly and ultimately the unwelcome forecast of its 'ultimate death'.

Nutrition: diatoms, protozoons and other minute food organisms which reach the radial canals with the current of water are tackled by the choanocytes, which digest them and pass on the digested material to the wandering amoebocytes which transport it to the various parts of the body. Digestion is intracellular; the undigested remains are thrown away into the radial canal wherefrom they are washed away by the current. *Mouth* and anus are completely absent.

Respiration is *aerobic* and oxygen dissolved in water is absorbed by the cells of the sponge by diffusion. Sycon dies if kept in water devoid of oxygen.

Excretion occurs through the agency of water into which the excretory waste is expelled.

Behaviour: *Sycon* is completely incapable of locomotion. There is no system of co-ordination and hence responses to stimuli are very simple. There are no nerve cells and no sense cells. The region around the osculum and in its immediate neighbourhood is slightly more sensitive than other regions. The regions where the *myocytes* are found e. g. around the osculum and pores, show more pronounced activity involving contractions and expansions. Stimuli applied to the oscular sphincter result in the opening and closing of the osculum: narrowing it or widening it. A trace of transmission occurs through the protoplasm of different cells.

The behaviour of *Sycon* is not co-ordinated and is not controlled by any central agency such as the nervous system in case of metazoa. When a harmful chemical is placed in water, the ostia are closed due to contraction of porocytes; all the pores are closed showing thereby that the sponge possesses a *behaviour-pattern* conducive to its welfare.

Regeneration, "the process by which the body returns to its specific form when that form has been disturbed by loss of a part" is found as a marked capability in Sycon like all other sponges.

Reproduction: The agents of asexual reproduction, *gemmules* are not found in Sycon. Only sexual reproduction occurs. The archaeocytes give rise to *sperms* and *ova* which are developed immediately below the epithelium of the radial canals; the embryos are also found in the same position. *Sycon* is hermaphrodite. Cross-fertilization is the rule due to maturity of sperms and ova at different times.

The cleavage is total or *holoblastic*. A sixteen celled hollow **blastula**, with upper eight smaller and lower eight larger cells, is formed; there is an *opening* on the lower side; the upper small cells develop flagella on their inner side. This stage is called *stomoblastula*. An **inversion** of cells, then, occurs, the embryo turns inside out through the opening so that the flagella now come on the outer side; the embryo is now called **amphiblastula** which leaves the mother through the osculum. Amphiblastula is a *free swimming larval stage* and swims with its anterior flagellated hemisphere anteriorly directed. The cells have already become much more numerous and continue to multiply. The flagellated region is invaginated and becomes overgrown by the large granular cells (lower cells); this second inversion is called *embolic gastrulation* and results into a *gastrula* which settles down on some rock or sea-weed with its mouth (the place of inversion in the flagellated hemisphere) downwards; this mouth closes soon. As a result of second inversion, the flagellated cells again come on the innerside; collared cells, archaeocytes and amoebocytes are formed from the flagellated cells; a *middle layer* develops and the dermal epithelium, *pinacocytes*, *porocytes* and *scleroblasts* develop mainly from the first 8 macromeres. In the centre, the *spongocoel* makes its appearance and *osculum* is formed at the free end. Now a simple-sponge stage known as the **olynthus** stage is formed. Mesogloea develops more, the body wall gets thickened and folded and ultimately a complicated canal system characteristic of the adult *Sycon* is ultimately formed.

The embryology of Sycon presents the remarkable feature of the *inversion of cell-layers*: the outer layer of the embryo becomes the inner layer of the adult, the inner layer of the embryo becomes the outer layer of the adult. Thus the outer layer has been aptly termed the *dermal layer* and *not* as the ectoderm; the inner layer has been likewise termed the *gastral layer* and *not* the endoderm. The terms 'ectoderm' and 'endoderm' are not used in case of Porifera.

Points of difference and similarity between Porifera and Coelenterata

The *apparent* points of similarity are: (i) the presence of a large cavity in the interior of the body (ii) an opening is found at the free end: *mouth* in the Coelenterata and *osculum* in the Porifera (iii) the *mesenchyme* is not well developed (iv) both porifers and the coelenterates have a sessile habit (v) budding occurs in both and (vi) the larvae in the two cases *appear to resemble*. **It may be remarked that except the points (iv) and (v) all other features are only false points of correspondence and can hardly be enlisted as points of similarity.** The coelenteron is not homologous to the paragaster and nor the mouth corresponds to the osculum.

The porifera differ from the Coelenterata in the following important features: (i) the osculum of the Porifera does not correspond to the mouth of the coelenterata; both developmentally and physiologically the osculum is completely a different structure; the **osculum** is an *exhalant aperture* while the mouth is chiefly meant for intaking, being an inhalant aperture; (ii) the Porifera lack the nematocytes which are commonly found in coelenterates (iii) the wall of sponges is perforated while that of coelenterates is continuous (iv) the Porifera possess *choanocytes* which are not found in coelenterates and (v) the cell-layers are inverted in case of Porifera while in the coelenterates the embryonic ectoderm and the endoderm maintain their position in the adult.

23

Canal System in Sponges

Describe the structure and function of the various types of canal system in the Porifera.

The arrangement of passage ways in the body leading from the incurrent dermal pores to the spongocoel and then out through the osculum is known as the canal system in sponges. The arrangement of these *passage-ways* differs in various sponges particularly in the distribution of choanocytes : the canals lined by collar-cells are called *flagelleted chambers*; the canals where no choanocytes are found are lined by flattened epithelial cells. The canal system besides presenting grades of structural complexity is also of considerable physiological importance. An increase in complexity of the canal system has occurred progressively in sponges to attain an increased *choanocyte surface* which is really the physiologically most-active internal surface of the sponge. With the increase in the number of choanocytes, the feeding capacity also increases. Multiplicity of choanocyte chambers makes available a larger choanocyte surface to the sponge without corresponding increase in its own body-volume : thus the surface is increased in proportion to the body-volume.

Three main types of canal system are found in sponges :

I. the **Ascon type** e. g. *Leucosolenia,*
II. the **Sycon type** e. g. *Sycon*
III. the **Lecuon type**
  (a) *eurypylous system*
  (b) *aphodal system*
  (c) *diplodal system*

I. **Ascon type of canal system** found in *Leucosolenia* and the *olynthus stage* (a stage in the development of calcareous sponges). The body is simple vase like and the body wall is thin and bears on its surface incurrent pores each of which is a perforation in a single cell the *porocyte* and which directly leads into the paragaster. No separate incurrent canals, radial canals etc. are found. The entire paragaster or spongocoel is lined by choanocytes. The course of water current is: dermal pores (ostia) —→spongocoel—→osculum—→exterior. The body wall consists of an outer layer of flattened cells known as *pinacocytes*, an innermost layer of *choanocytes* and an intermediate layer designated as *mesenchyme* which contains skeletal elements, the spicules, a matrix of jelly and various kinds of cells: amoebocytes, scleroblasts, archoeocytes etc. (See fig. no. 94 on page 118 and fig. no. 91 page 115).

II. **Sycon type of canal system** (found in *Sycon* and *Grantia* etc.) : If the body wall of an asconoid sponge is assumed to give out thimble shaped outpushings all over, at regular intervals and if the epidermis was to "grow over" the distal blind ends of these outpushings leaving minute apertures on its surface, we will have a thickened body wall with canals characteristic of *Sycon* : *incurrent canals, radial canals* (flagellated canals) etc. ; the choanocytes will be found to line the inner surface of the outpushings. Between every two adjacent outpushings we will have tubular spaces lined by epithelial cells and lacking choanocytes ; these spaces would open to the exterior by minute pores and would be ending blindly towards the paragaster ; it is into these 'incurrent canals' that the water first of all comes through the *ostia* of the pore-membrane. The *adjacent incurrent* and *flagellated canals* intercommunicate by means of apertures known as *prosopyles*. Each flagellated canal opens towards the paragaster, first through the apopyle into the *excurrent canal* which opens into the paragaster by a wide *gastric ostium*. The paragaster is lined with flattened epithelial cells and *not by the choanocytes*. The spongocoel opens to the exterior by the osculum. The main features of the sycon type of canal system are :

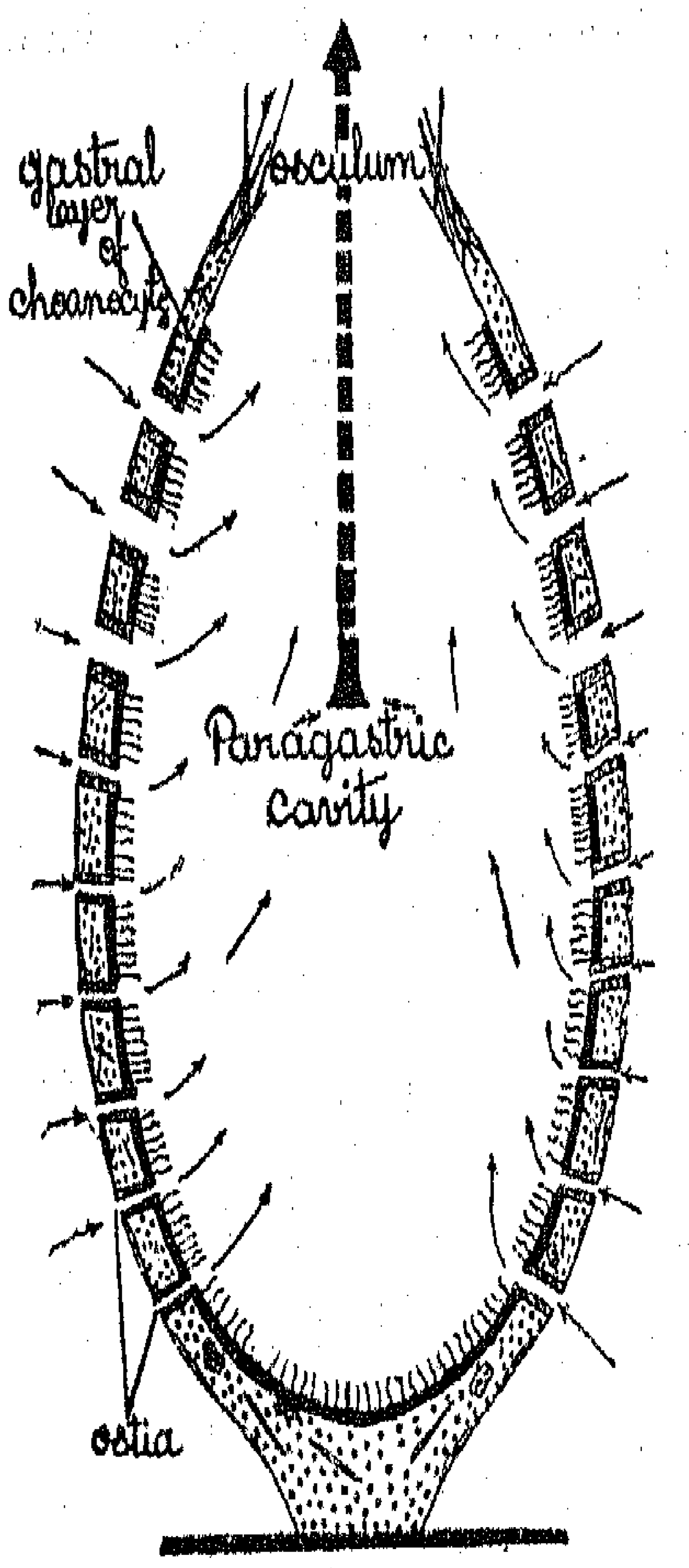


Fig. 99. Diagram of an Ascon type of sponge ; the arrows indicate the course of water current.

(1) the *dermal pores* (ostia) and the *inner pores* opening into the paragaster are not in direct opposition, (2) the body wall is traversed by two sets of canals running parallel to each other : the *incurrent* and the *radial canals*, (3) the paragaster is lined by epithelial cells and not by choanocytes, (4) the choanocytes are restricted to the radial (or the flagellated) canals and (5) the body wall is thicker (due to greater development of mesenchyme) than that of the ascon type. The course of water-current is from the exterior—→dermal incurrent pores—→incurrent canal —→prosopyles—→radial canal—→apopyle—→excurrent canal —→gastric ostium—→paragaster—→osculum—→to the exterior. (See fig. 97).

In advanced syconoid sponges epidermis and mesenchyme spread over the surface of the sponge forming the dermal cortex; the ostia pierce through it and lead into the incurrent canals; in some cases large cortical or subepidermal spaces may be present into which the ostia first lead prior to their finally opening into the incurrent canals.

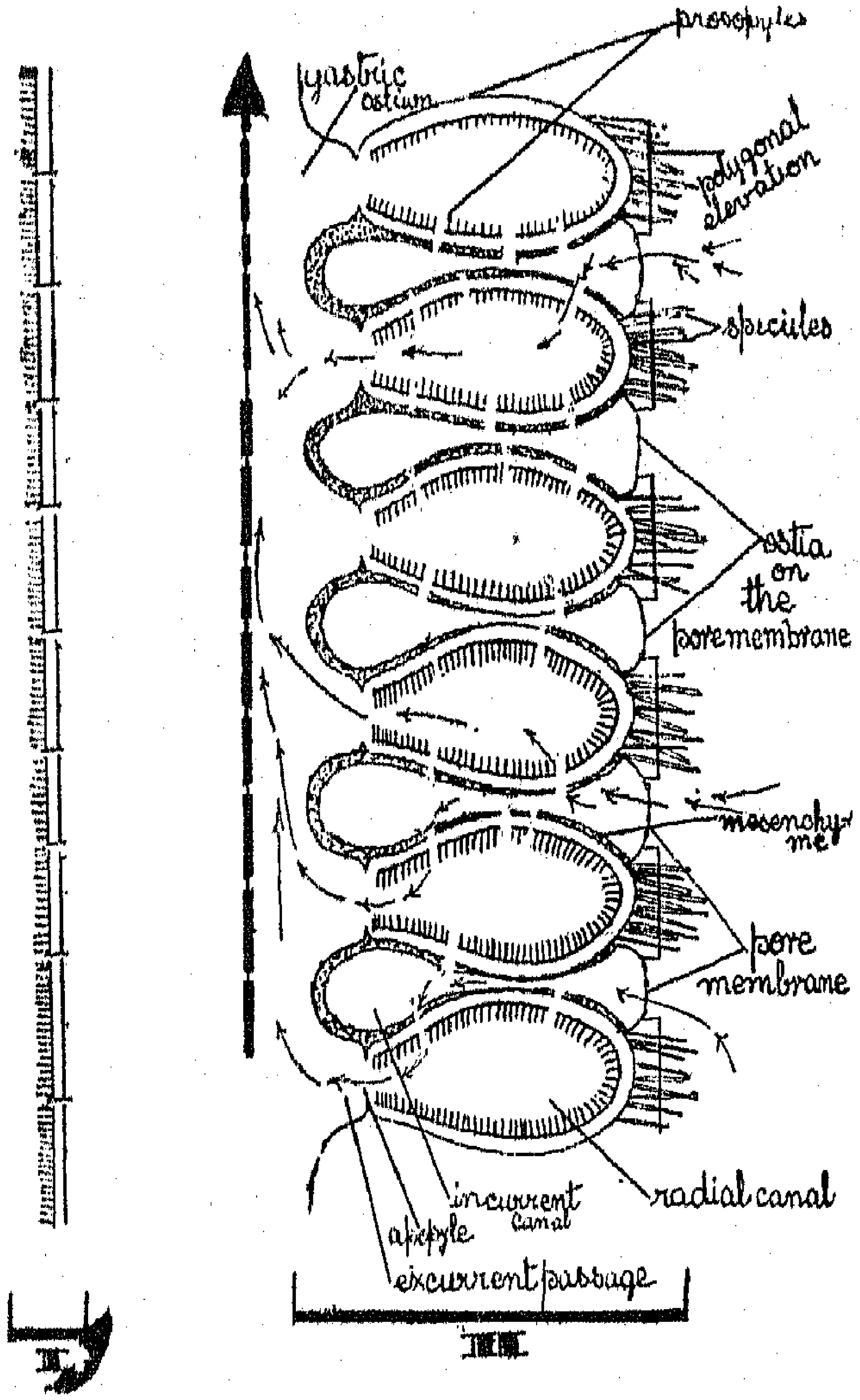


Fig. 100. Theoretical derivation of the II from the I, represents the body wall of an ascon type and II represents the body wall of a syconoid sponge (Diagrammatic).

III. **Leucon type of canal system:** A further outfolding of the flagellated chambers occurs as a result of which the *flagellated chambers* become arranged in groups about a main excurrent canal. The dermal pores (or ostia) lead into the inhalant canals which branch irregularly through the mesenchyme, their branches and sub-branches ramifying in the thick dermal cortex. The dermal cortex is found immediately inner to the dermal epithelium and contains canals and spaces which communicate on the one hand with the exterior and on the other with more deeply situated subcortical spaces which communicate with the flagellated chambers through canals lined by flattened epithelium. The dermal cortex has plenty of skeletal elements besides branched connective tissue cells.

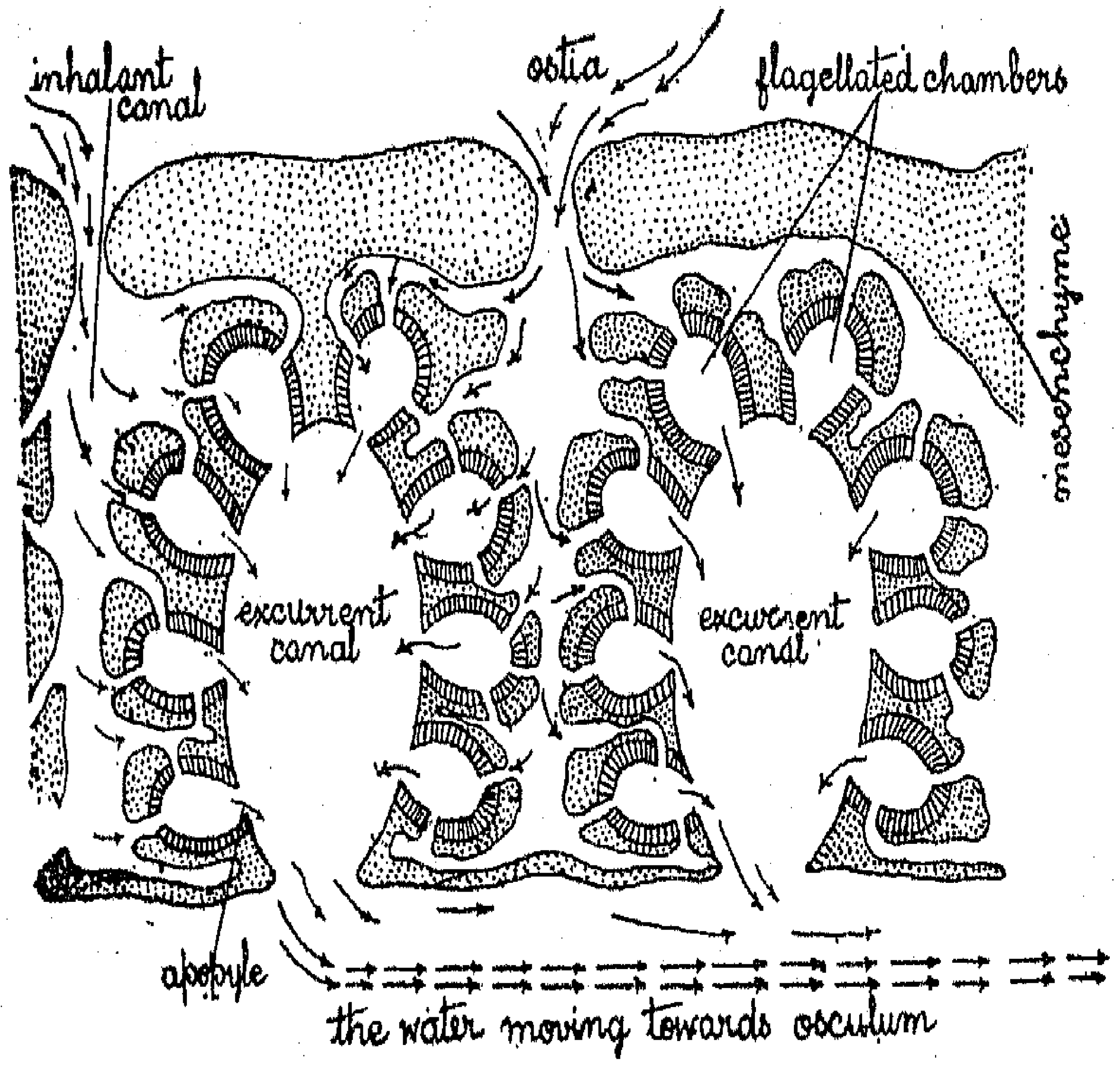
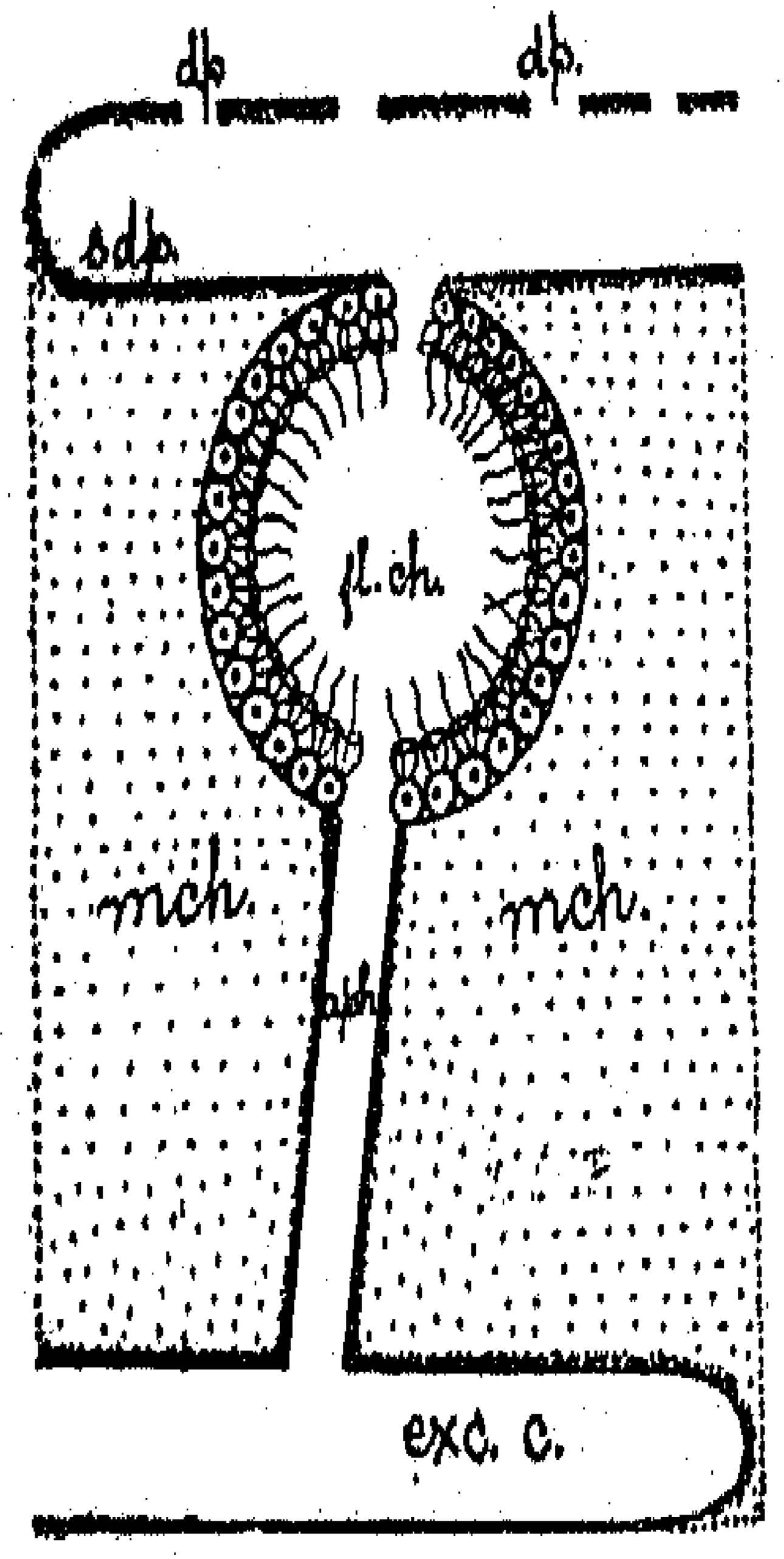


Fig. 101. Leucon type of canal system.

In highly developed sponges, the paragaster is more or less obliterated due to profuse growth of mesenchyme, development of subdermal cavities, branching of inhalant canals and multiplication of flagellated chambers. The flagellated chambers communicate with the paragaster by the excurrent canals (lined with flattened epithelial cells) through *apopyles*; these excurrent canals unite to form larger and larger canals, the largest of them leading to osculum.

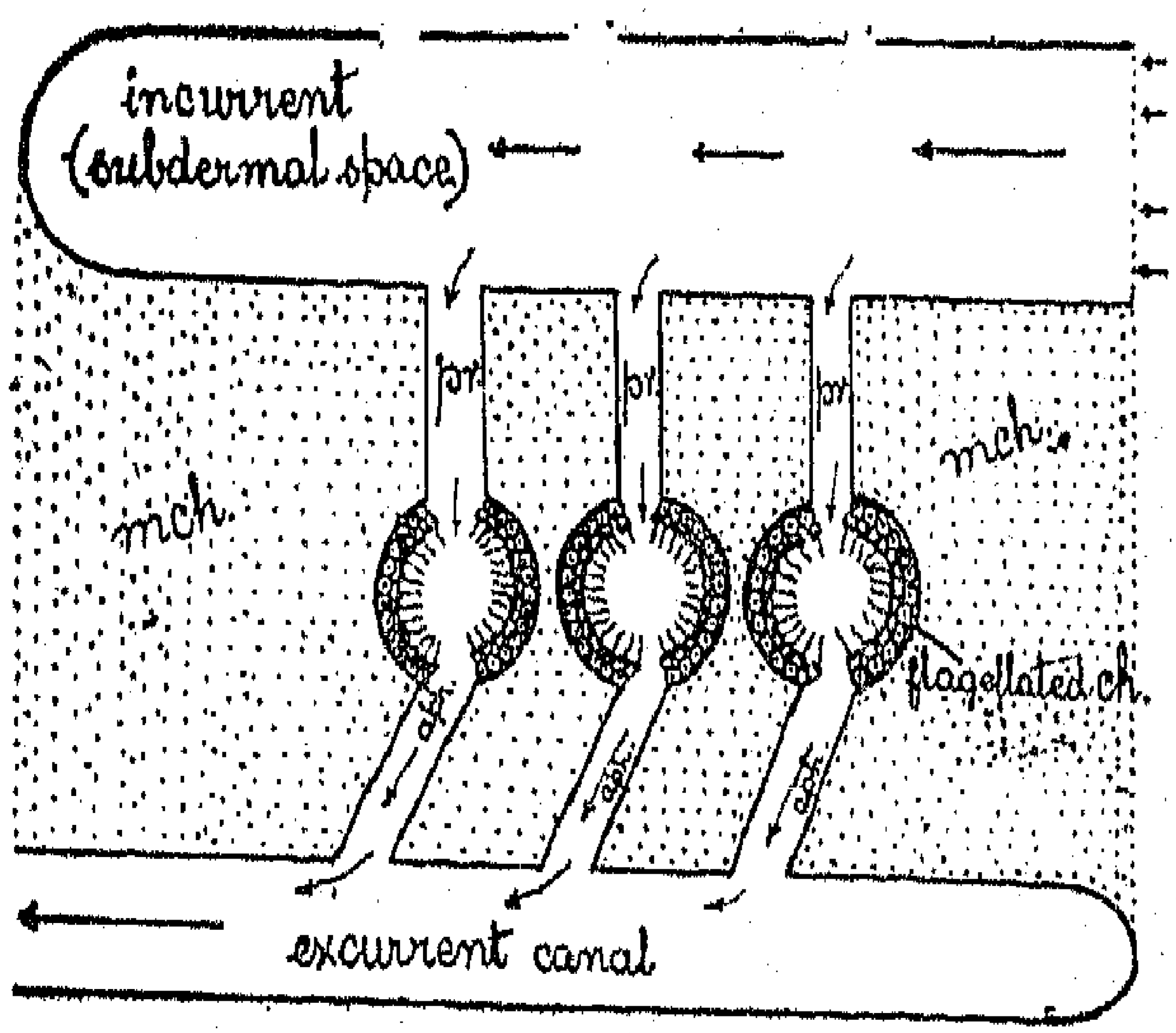


(a) **Eurypylous system:** when the apopyles open directly into the mouth of the excurrent canals the system is termed the eurypylous system e. g. *Leucandra*, *Leucetta*.

(b) **Aphodal system:** when the apopyles do not directly open into excurrent canals, but a narrow canal, the *aphodus* intervenes between the flagellated chamber and the excurrent canal, the system is termed as the **aphodal system.**

Fig. 102. The Aphodal system (Diagrammatic sketch) dp, dermal pore, sdp., subdermal space., aph., aphodus, exc. c., excurrent canal, mch, mesenchyme.

(c) **Diplodal system :** in some cases, a narrow tube known as **prosodus** is found between the incurrent canal and the flagellated chamber in addition to the aphodus ; such a system has been termed as the **diplodal system.**



pr., prosodus. aph., aphodus. mch., mesenchyme. The arrows indicate course of water current.

Fig. 103. The Diplodal system (Diagrammatic).

The main features of the leuconoid canal system are (1) the restriction of choanocytes to small and round chambers, (2) the presence of complex incurrent and excurrent canals (3) great development of mesenchyme and (4) the obliteration of paragaster to a smaller or greater extent. The total area of the choanocyte surface is greatly increased in the system with consequent promotion in the efficiency of the sponge. The **leuconoid type** of canal system is found in vast majority of sponges and has an efficiency superior to the asconoid as well as the syconoid systems ; it is found in *Leucandra, Leuconia, Oscarella Spongilla* etc.

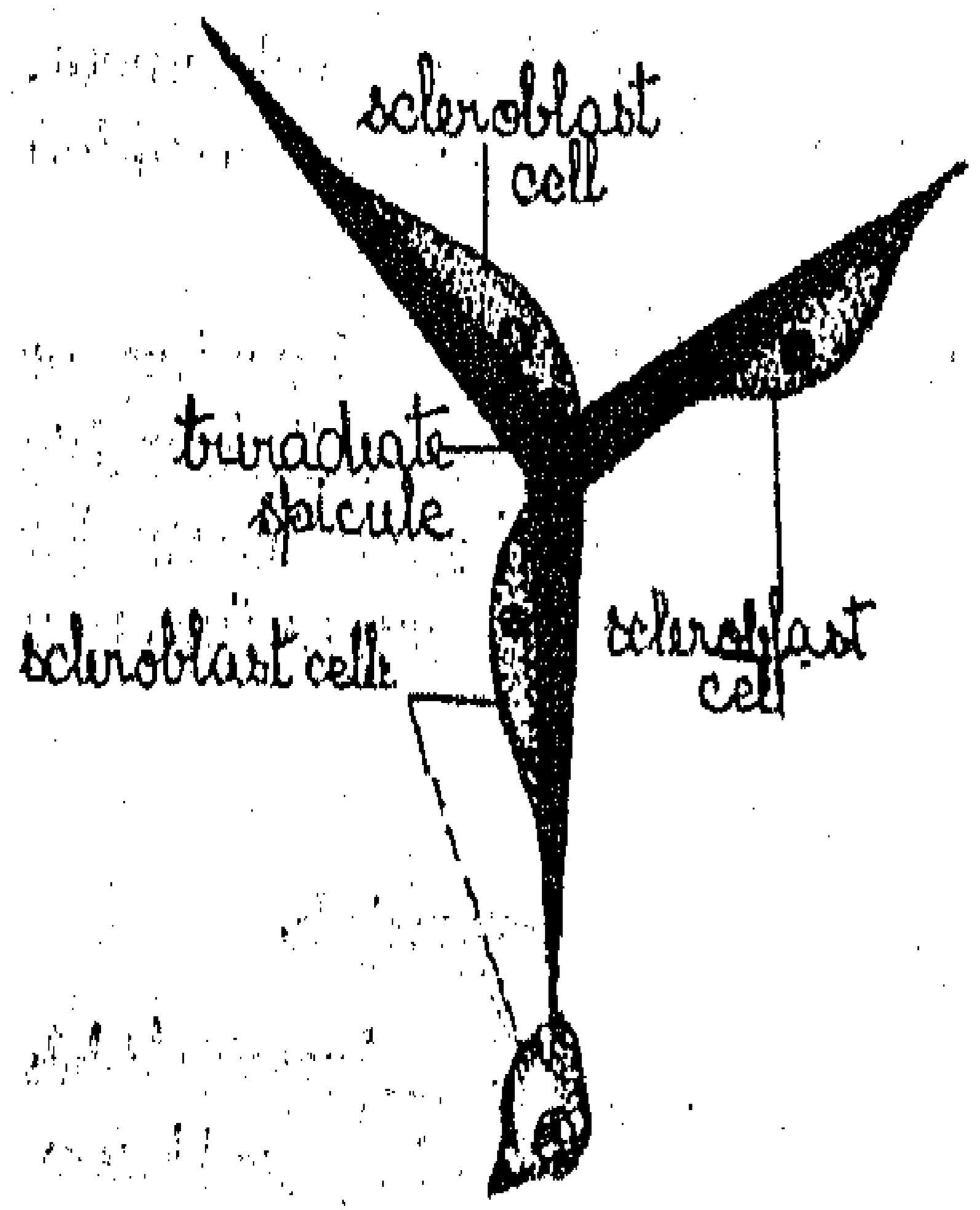
24

Important Short Notes (Porifera)

Skeleton in Porifera : The elements furnishing the important function of skeletal support in sponges are microscopic and fall into three categories :

(i) **Calcareous spicules** which are definite tiny bodies having a crystalline appearance, a spiny surface and an axis of organic material with deposits of calcium carbonate ; calcareous spicules are found in *Leucosolenia, Sycon, Grantia, Clathrina* etc. : all the members of the class Calcarea. The calcareous spicules may be monaxons, oxeote, triradiate or tetra-radiate i. e. needle shaped, spear shaped, three-rayed and four-rayed respectively. Each spicule is developed from cells known as *scleroblasts.* Three scleroblast cells co-operate in the secretion of a triradiate spicule.

(ii) **Siliceous spicules** have a deposit of *silica* which is extracted from water like calcium carbonate. The siliceous spicules have a larger variety than that of calcareous spicules, they are secreted by *silicoblast cells.* The siliceous spicules are the sole skeletal elements in the class *Hexactinellida* e. g. *Euplectella, Pheronema* and *Hyalonema* : in all these forms, the entire skeleton consists of siliceous spicules bound together by a siliceous cementing substance.



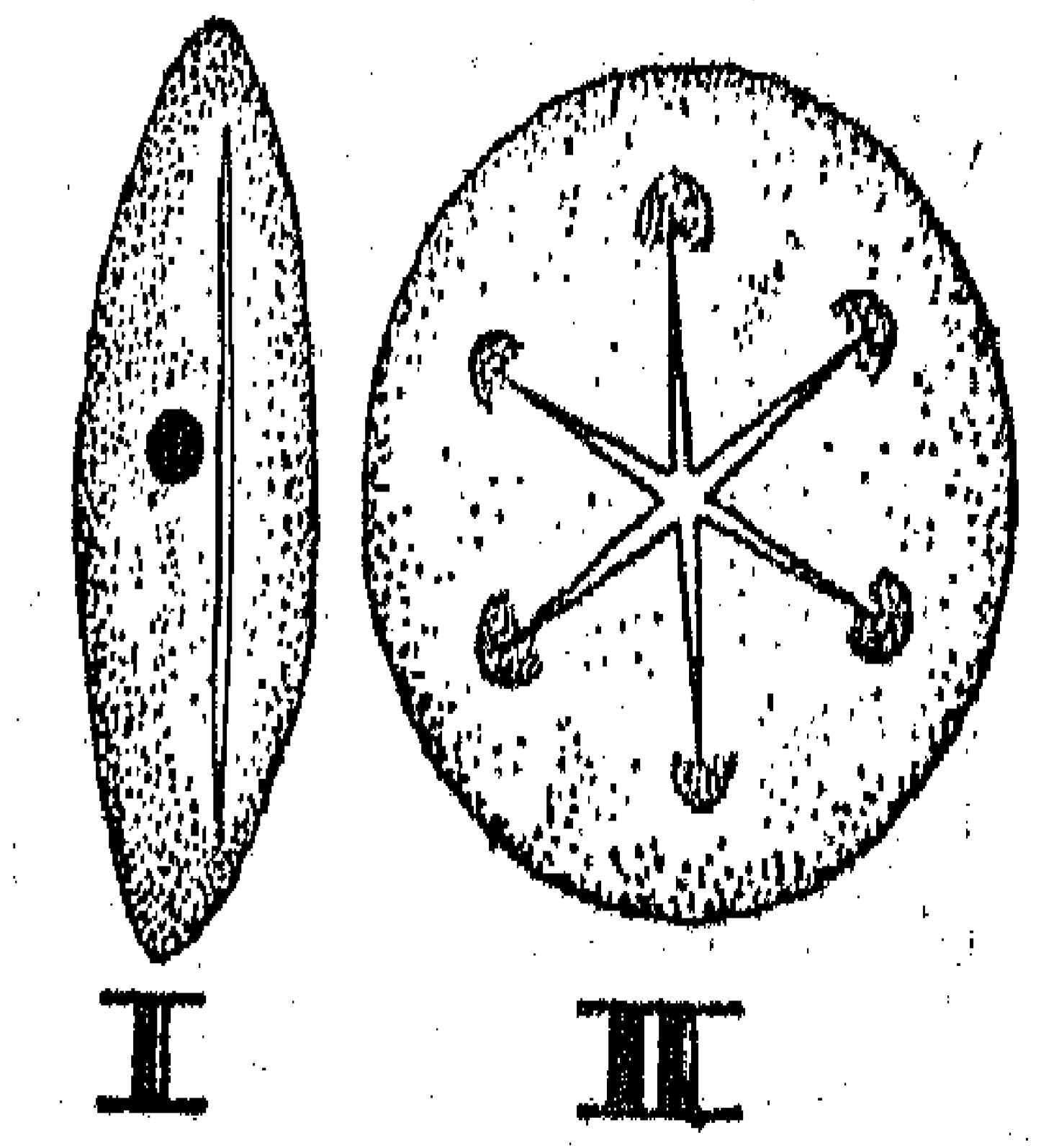


Fig. 105. Development of siliceous spicules I monaxon and II hexactinal spicule.

← Fig. 104. Development of a triradiate calcareous spicule.

(iii) **Spongin fibres** : the spongin is a horny protein substance allied to silk in its chemical composition and contains a good amount of iodine. In the order **Keratosa**, i. e. in *Euspongia* and *Spongelia* skeleton is formed solely of spongin fibres which are extremely fine threads, branched, anastomosed and interwoven into a firm supporting structure. The fibres contain a granular core and a surrounding deposit of spongin in concentric layers; these fibres are elastic and hence constitute a good skeletal element. The sponges in which spongin fibres are the sole skeletal elements are also known as 'horny sponges'. The cells which secrete spongin fibres are known as **spongoblasts.**

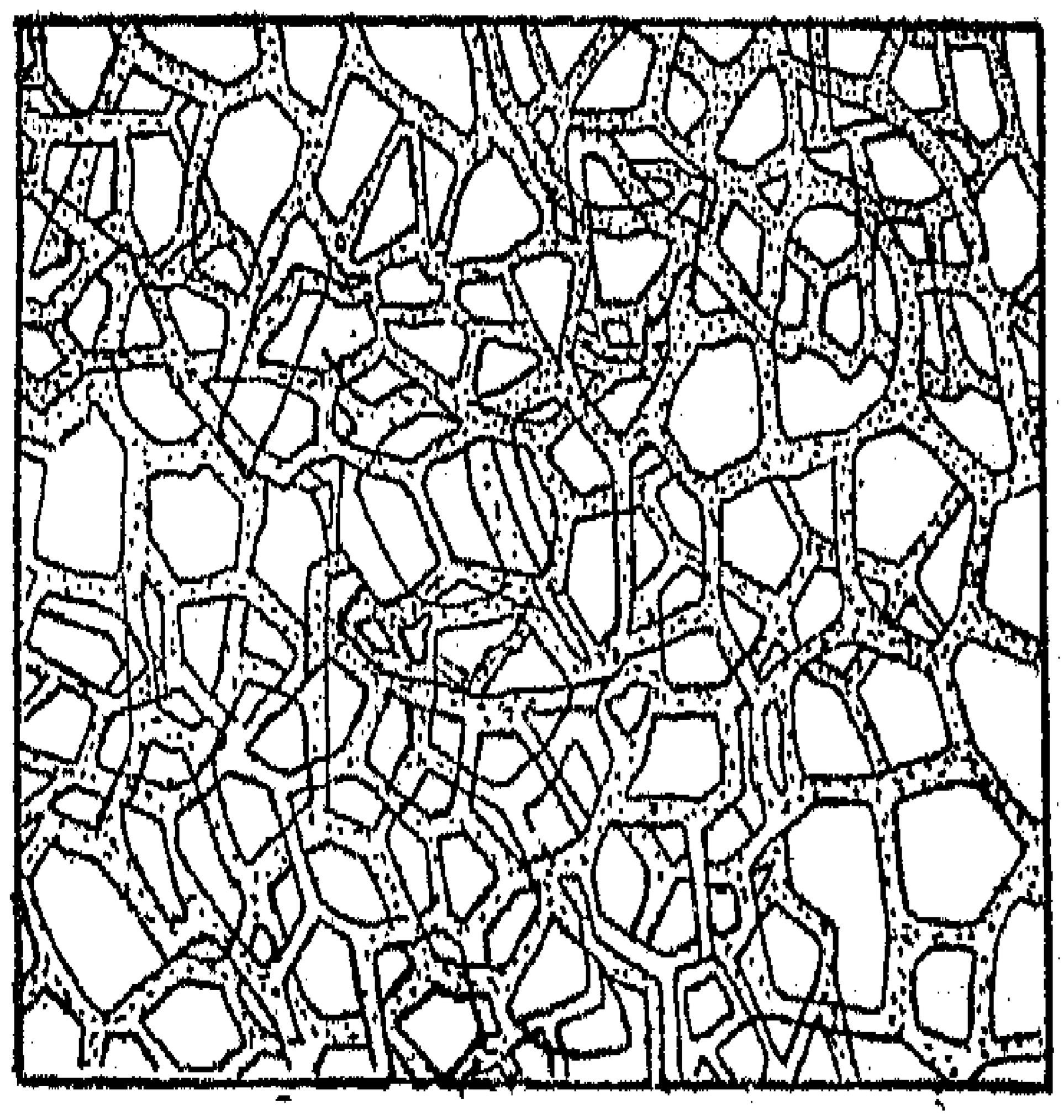


Fig. 106. Spongin-fibres under microscope.

Gemmules: these are a kind of internal buds consisting of 'groups of cells' which become detached from the parent and which develop into new adults by an independent development. The gemmules are developed from special cell-masses imbedded in the general mesenchyme.

The gemmules are capable of withstanding freezing or drought and thus help the race in tiding over unfavourable environmental conditions. They possess firm and stout coats for the purpose. The gemmules also serve the important function of **dispersal.**

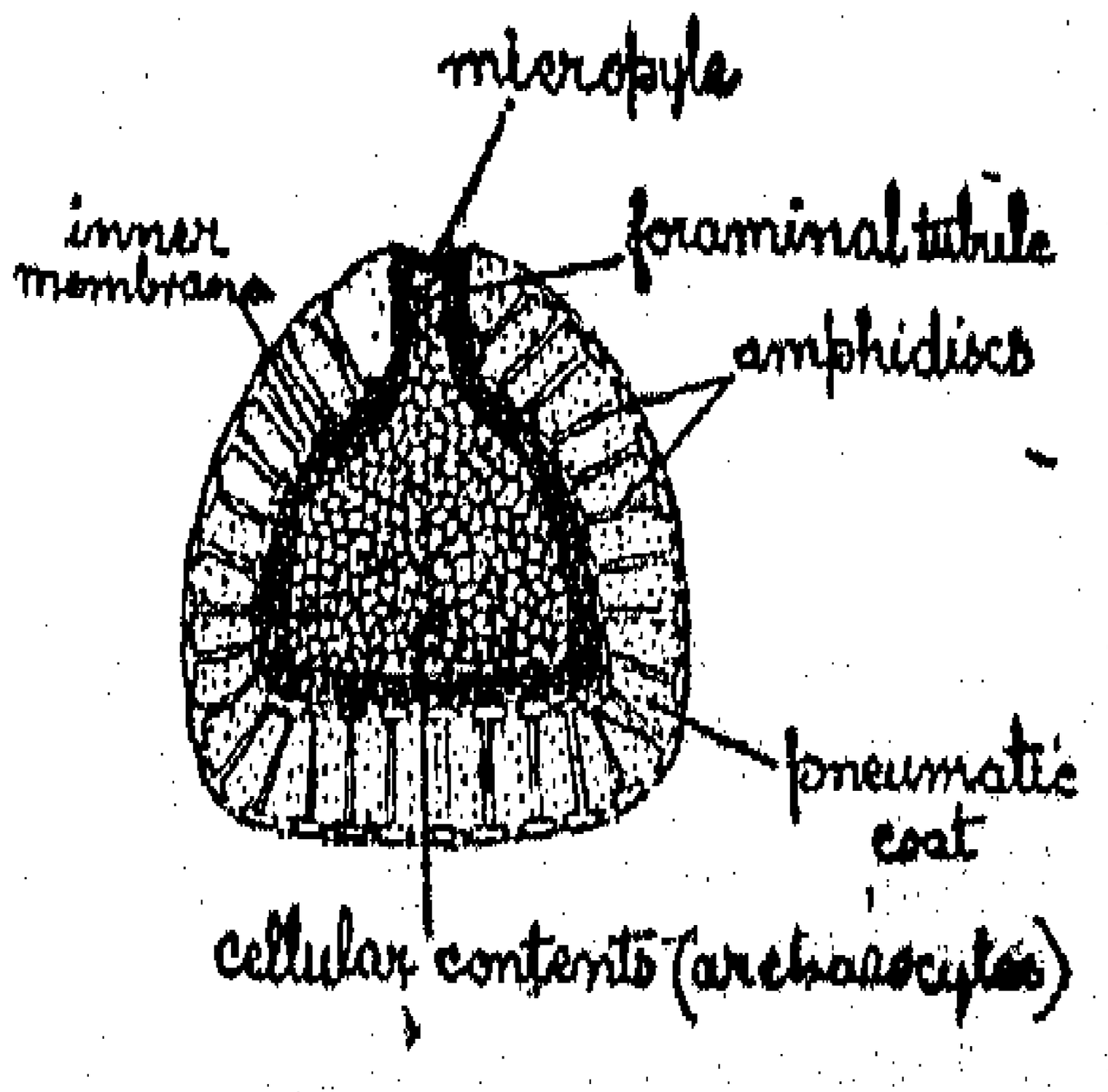


Fig. 107. Structure of gemmule of spongilla as seen under microscope.

Gemmules bring about asexual reproduction and are formed in **fresh water sponges** (family *Spongillidae*). When the mother sponge ceases to live, the gemmules remain attached to its old skeleton, some of them sink down while others keep floating; assisted by strong winds they get distributed to places 'far off' from the parents as well as from each other. During development of gemmule, a cluster of archaeocytes moves from the dermal layer to the deeper parts of body; these archaeocytes are generously fed by the amoebocytes (nurse cells) as a result of which they acquire sufficient food reserves. Certain amoebocytes come to envelop the mass of archaeocytes completely; these amoebocytes secrete a hard and thick inner chitinous membrane and an outer thin membrane. The scleroblast cells rush up and carry spicules to the developing gemmule: the siliceous amphidisc spicules become arranged by the scleroblasts radially between the outer and the inner membranes. These scleroblast cells form the air chamber. The radially arranged spicules lie between the inner and the outer membrane and form a fairly thick layer which contains spaces giving the gemmule a certain buoyancy: the layer is therefore also known as the **pneumatic coat.** The fully formed gemmule has an opening known as the micropyle which remains closed except when the cells have to escape to the exterior at an opportune moment on return of favourable conditions. The *micropyle* often lies at the summit of the *foraminal tube* which is a tubular extension of the external membrane.

In our country, *gemmules* are produced immediately before the summers and tide over the dry and hot season; in the cold countries they are produced towards the end of the year and withstand the extremes of cold; in spring the living cells of the interior escape to the exterior through the micropyle and develop into adults.

When the favourable environmental conditions return, the gemmule hatches and the cells contained within, which have preserved 'life', emerge to the exterior through the micropyle and undergo 'arrangement and differentiation' thereby forming a new adult. In this development no cleavage occurs like that of ovum, but only clumping, arrangement and differentiation occur.

The multinucleate archaeocytes divide (while inside) and form uninucleate cells known as the *histoblasts.* It is these cells which come out through the micropyle, become arranged and get differentiated into choanocytes, porocytes and other cells constituting the body. Some of them are modified to form the scleroblast cells which secrete siliceous spicules. As a result, a complete sponge is formed in about a week's time. Some of the histoblasts which remain unchanged become phagocytic amoebocytes while others give rise to sex cells.

25

Classification of Porifera

[NOTE : *For the characters of Porifera see chapter no. 20, page 114*]

Porifera

- Class 1. **Calcarea** (*Calcareous skeleton*)
  - Order 1. **Homocoela** *Leucosolenia, Clathrina*
  - Order 2. **Heterocoela** (*Sycon, Grantia*)
- Cl. 2. **Hexactinellida** (*Six-rayed siliceous spicules skeleton*) Ex. *Euplectella*[1], *Pheronema, Hyalonema,*
- Cl. 3. **Demospongiae** (*skeleton when present : spongin alone or with siliceous spicules other than six rayed*)
  - Order 1 **Monaxonida** (*Monaxon spicules*) *Cliona*[1], *Suberites, Microciona, Spongilla, Tethya* etc.
  - Order 2 **Keratosa** (*Spongin alone*) *Euspongia*[1], *Hippospongia* etc. (Commercially important, shallow water forms)
  - Order 3 **Myxospongiae** (*Without skeleton*) *Oscarella, Halisarca*
  - Order 4 **Tetractinellida** (*Tetraxon spicules*) *Geodia, Plakina*

We will describe very briefly only the forms marked with an asterisk above.

Class 2. **Hexactinellida** includes deep sea sponges with a glassy appearance ; the skeleton consists of **purely siliceous spicules** of the **hexactinal** or the **'six-rayed' type** ; the rays may be a multiple of six. The dermal cells form a network of trabeculae by branching. The soft parts of the body are united by this trabecular net. The members are also called **glass-sponges.**

Euplectella (Venus' flower basket) : the skeleton is a priced exhibit of museums and its long curved cylindrical framework of spicules which supports the body is a marvel of beauty. The glassy body is cylindrical and very light. The osculum is remarkable for having a covering sieve-like plate of silica over it. On the body-surface are distinct projections known as **ledges.** At the

lower extremity are found very long filamentous spicules which help in fixing the animal to the sea-bottom. The prawn lives inside the body of **Euplectella** as a commensal. The decapod crustacean is known as *spongicola* which in its early developmental stage enters *Euplectella's* body through pores and grows inside the latter's body as a prisoner; it becomes grown up and remains imprisoned inside due to its large size making the escape impossible through the small pores of *Euplectella's* body. A male and a female *Spongicola* are found in *Euplectella* and hence the sponge is presented in marriages in Japan to felicitate the newly married human couple. *Euplectella* is found in the sea-bed in eastern seas, round about Borneo; it is particularly abundant near the Philippine islands.

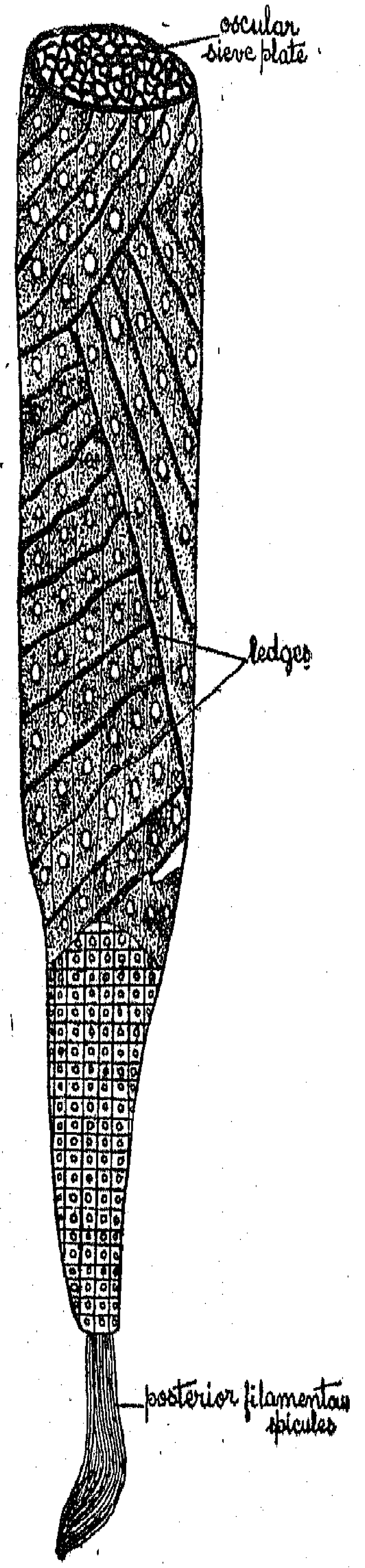


Fig. 108. Euplectella (Venus flower basket).

Class 3. **Demospongia**

Order 1. **Monaxonida**

Example : *Cliona* is a boring sponge; it makes a hole in a rocky substance and lives in a tunnel. It also bores the shells of molluscs and into calcareous rocks for protection. Cliona is cosmopolitan and its species are yellow green or purple.

Order 2. **Keratosa** (horny sponges) : skeleton made entirely of spongin fibres; are sponges of commercial importance.

Ex. *Euspongia* is the common bath sponge and owes its utility to its skeleton which can hold water in the fine spaces of the irregular spongin mesh work due to capillary action. It is found in the Mediterranean Sea, Gulf of Mexico and about the West Indies. The sponges are now artificially cultivated or 'cultured' by many industrial concerns to step up their production in order to meet their huge commercial demand. Small pieces are cut from the big sponge-body and are kept on cement blocks in the shores on a shallow bottom where water-currents rich in food and oxygen are constantly bathing them. In course of time the small parts grow into big sponges. They may be allowed to grow like this for as long as five years (or so) till they attain a marketable size. This method of production of sponge may be termed as 'artificial cultivation'. Euspongia is of many kinds: *glove sponge*, *Turkey-cup sponge*, *Hard-cup sponge* etc.

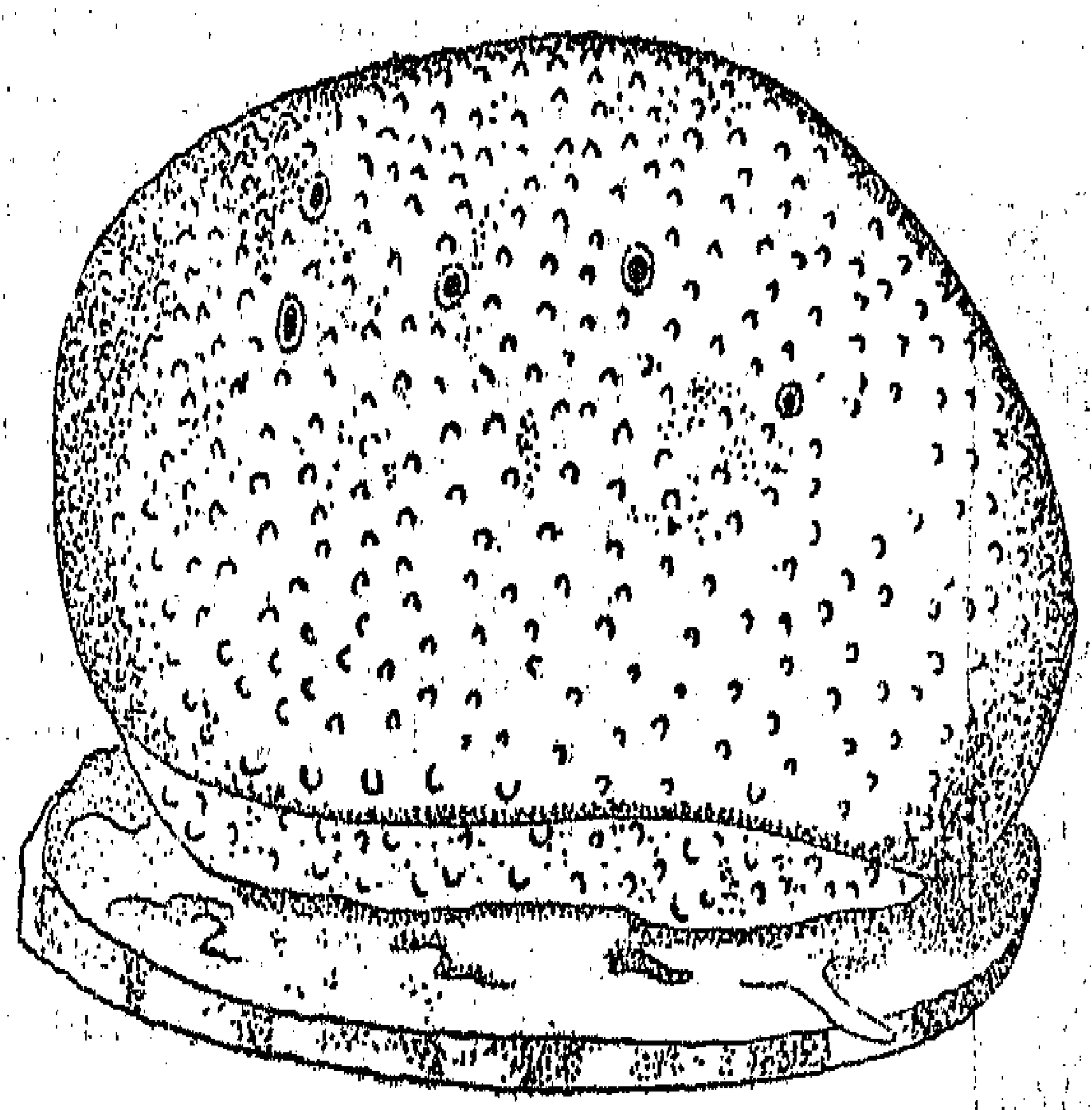


Fig. 109. Euspongia.

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27

Structure and Life-history of Obelia—Alternation of Generations—Homology of Polyp and Medusa

1. **Describe the structure of a medusa of** *Obelia* and **ive your views on its adaptational features.**
(L. U. B. Sc. Pass, 1952)

2. **Describe in detail the life-history of** *Obelia*.
(Agra 1946, Alld., 1948)

3. **What are homologous** structure? **Show by means f neat diagrams that a polyp of** *Obelia* **is homologous ith its medusa.** (Alld, 1951, 1955, Agra 1942, 1953)

4. **Describe the phenomenon of alternation of generaons as illustrated by the life-history of** *Obelia* **and explain s significance.** (L. U. B. Sc. Pass, 1954)

Obelia[1] is a marine branching colony : a zoophyte of common ccurrence in tide-marked levels with **three kinds** of zooids :) the *polypes* or *hydranths* which are hydra-like individuals mainly utritive in function, (ii) the *blastostyles* which are long cylindrical dividuals occurring mostly in proximal regions and (iii) the

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[1] Phylum Coelenterata is divisible into three classes (1) **ydrozoa** (2) Scyphozoa and (3) Actinozoa. *Obelia* belongs the class Hydrozoa. **Hydrozoa** are mostly colonial, with o main kinds of zooids (i) sexless nutritive zooids, the *polypes* d (ii) reproductive zooids the *medusae* which arise as buds om the polyp-colony. The medusae have a velum, a nerveng and well developed sense organs, muscular and nervous stems and *radial* and *circular* gastrovascular canals. The nads are ectodermal (most commonly) and the reproductive ements are discharged externally. The polyps have usually *id tentacles*; exoskeleton is found (horny perisarc or a massive eleton of calcium carbonate forming a coral). There are no rtical partitions in the coelenteron. There is no stomodaeum. the most typical forms (e. g. *Obelia*) the asexual generation presented by a branched sessile colony alternates with the sexual neration represented by a free-swimming medusa.

medusae which arise as hollow off-shoots from the blastostyle, lead a free-swimming life and reproduce sexually ; the medusae are the only zooids to bear gonads. Due to three kinds of zooids, the colony is described as **trimorphic**. The zooids are borne on

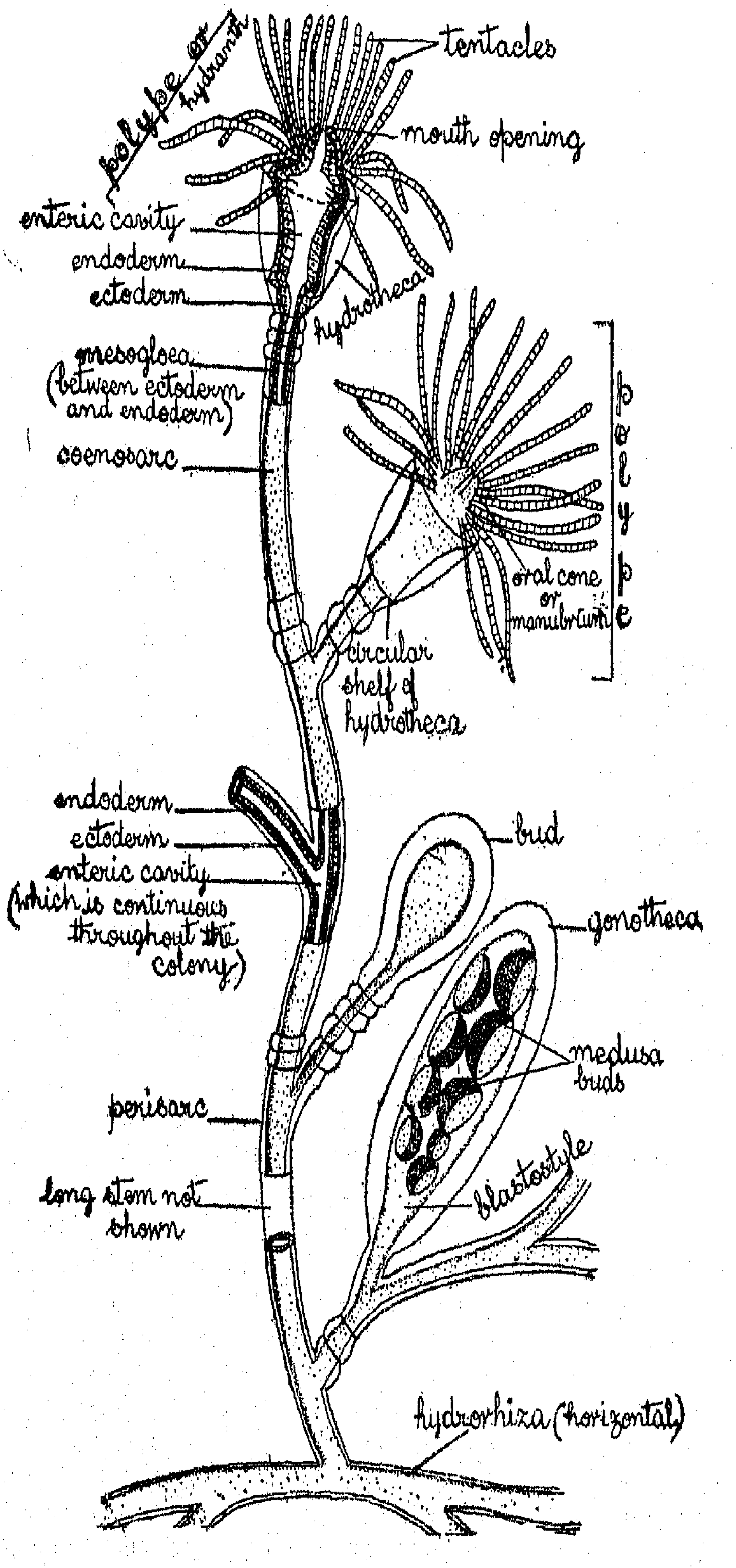

Fig. 113. Obelia colony.

branched filaments of which the horizontally running root-like hollow tubes which extend over the substratum (see-weeds, algae, rocks etc.) and form the base of the colony are called *hydrorhiza* and the vertically springing stems which branch in a cymose fashion bearing individuals at the tips of alternate branches are called *hydrocauli* (singular hydrocaulus).

The branching stems are all hollow ; the tubular cavity inside them is the *coelenteron* or *enteron* which is continuous throughout the colony and also extends into the zooids where it expands considerably. The enteron of the entire colony is continuous and contains a fluid 'the gastrovascular fluid'. The enteron is lined by ciliated endoderm cells ; due to the action of these cilia and rythmical contraction and expansion of polypes, the gastrovascular fluid exhibits flickering movements circulating in the entire colony and ensuring uniform distribution of nutrition to all its parts.

The tubular branching filament is completely invested by a thin transparent noncellular and cuticular layer known as perisarc ; the perisarc is made up of chitin and is secreted by the ectodermal layer lying immediately beneath it. The *perisarc* serves as a protective exo-skeleton of the colony. The living cellular layer of the tubular filaments which encloses the enteron is known as the *coenosarc.* The coenosarc is enveloped by the horny perisarc. The *coenosarc* is made up of an *outer ectoderm* and an *inner endoderm* and the intervening cell-less and structureless **mesogloea** or **supporting lamella.** These three layers also form the body wall of all the zooids and are continuous throughout the colony. Round the body of *polypes* (leaving the manubrium and the tentacles) and the *blastostyles,* the perisarc is produced into cup-like investments known as *hydrotheca* and **gonotheca** *respectively.*

Near the narrow basal end of the polyp, the hydrotheca forms a circular shelf perforated in the centre ; through this perforation, the basal end of the polyp is continued into the coenosarc of the common stem. At times, particularly when stimulated, the polyp retracts inside the vase-like hydrotheca with contracted tentacles bent together over the manubrium into a compact mass.

Of the three kinds of zooids, the **polyp** and the **blastostyle** reproduce *asexually* while the **medusa** gets detached from the colony, leads a free-swimming life, bears gonads and produces *ova* and *sperms.* Thus *the medusa represents the sexual generation* and reproduces sexually.

1. The **polyp** or **hydranth** is a *nutritive zooid* specialised for the capture of food, its ingestion and digestion. The polyp has a yellowish colour and a hollow more or less cylindrical body built on a general plan very similar to that of *Hydra.* The tentacles of Obelia's polyp are solid but those of Hydra are hollow. The **polyp** is really an expansion of the coenosarc with its body

encased in the transparent **hydrotheca** (except for the manubrium and the circlet of tentacles). The distal end of the polyp has a conspicuous *oral cone or manubrium* bearing a mouth opening at its summit. The base of the conical manubrium is surrounded by a ring of 26 to 30 elongated, *solid*, finger like, flexible and contractile processes known as tentacles. The tentacles have a solid axis of a single row of endoderm cells.

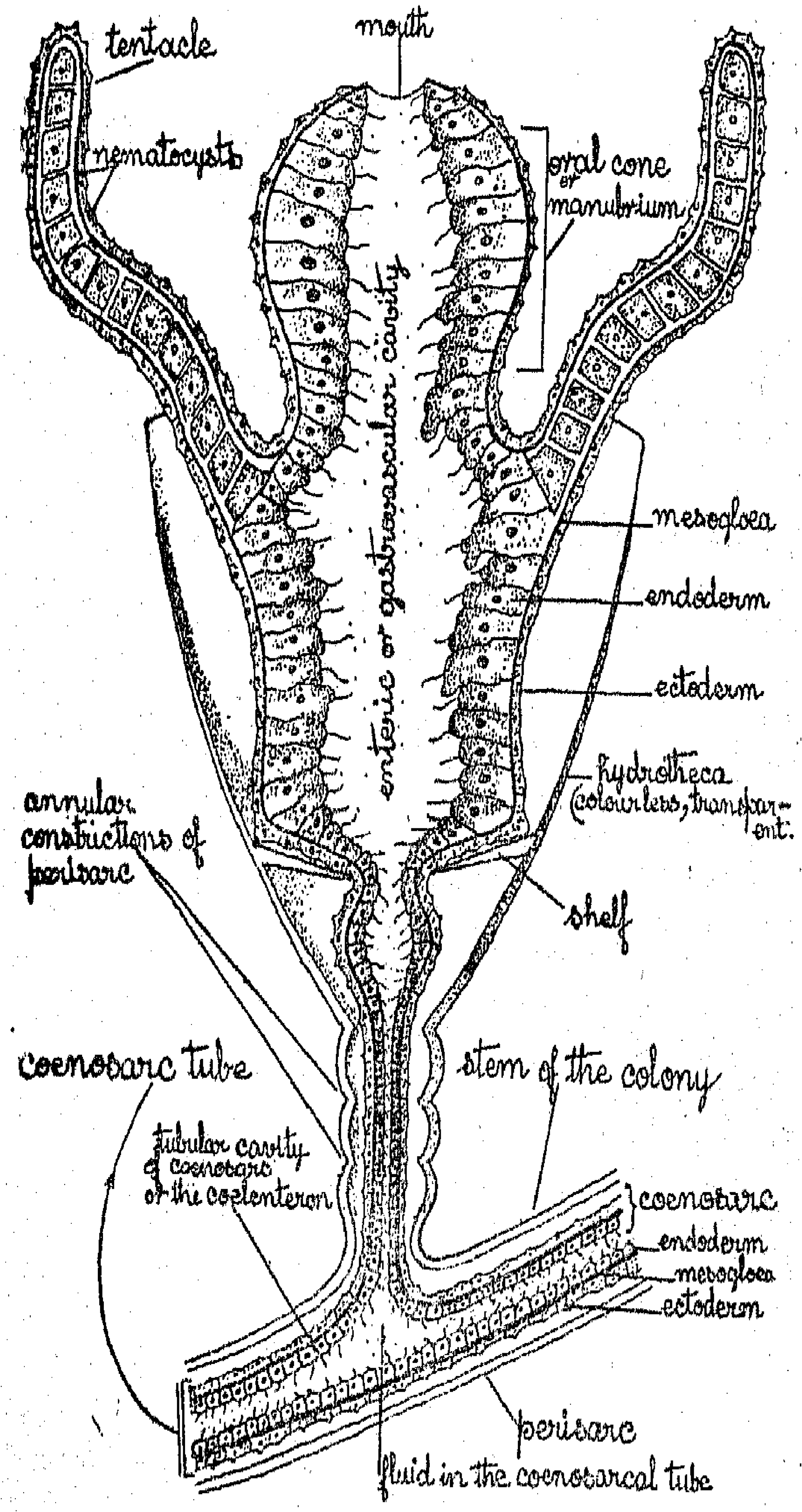
tentacle
mouth
nematocysts
oral cone or manubrium
enteric or gastrovascular cavity
mesogloea
endoderm
ectoderm
hydrotheca (colourless, transparent.
annular constrictions of perisarc
shelf
coenosarc tube
stem of the colony
tubular cavity of coenosarc or the coelenteron
coenosarc
endoderm
mesogloea
ectoderm
perisarc
fluid in the coenosarcal tube

Fig. 114. Vertical section through a polyp of Obelia with a portion of stem.

This *endodermal core* of *tentacles* is surrounded by a layer of *mesogloea* and the outermost covering of the tentacle is formed of ectoderm. A layer of *unstriped muscle fibres* found in tentacles between the ectoderm and the mesogloea makes the tentacles *contractile*.

At the extremity of tentacles, the ectoderm has imbedded in it, a very large number of *nematocysts* which initially develop inside the cnidoblast cells in the proximal region of the polyp at its base in the coenosarc but later on, migrate to the distal regions of the polyp: the ectoderm of the tentacles. The tentacles are armed with batteries of nematocysts and act as organs of food-capture. The *tentacles* entangle the paralysed or killed prey and by their bending movements carry it towards the mouth. The manubrium which is itself capable of great dilation and contraction, keeps ready with open mouth to receive the prey brought by the tentacles; the prey is ultimately swallowed,

The **body wall** of the polyp along with the wall of the manubrium is made up of an outer *ectoderm*, an inner *endoderm* and the intervening *cell-less, structureless* and *transparent mesogloea* or the *supporting lamella*. Both the *ectoderm* and the *endoderm* have the nature of a *columnar epithilium*; the endoderm is thicker than the ectoderm. The ectoderm is made up of large conical cells with their bases towards the outerside; these cells are *epithelio-muscular cells*; in between their inner narrow apices, spaces are left in which are found small and rounded *interstitial cells* and *nerve cells* bearing branched neurites and remarkably lacking axons. The enteron of polyp is lined by large endoderm cells which bear *pseudopodia* projecting into the enteric cavity. These *pseudopodia*, which can be formed and withdrawn, engulf the half-digested food-particles lying in the enteron. The pseudopodia can be withdrawn and replaced by long and vibratile *flagella* which protrude into the enteric cavity and stir the gastrovascular fluid containing the food particles. Interspersed between the large endodermal cells are found *gland-cells* which secrete a digestive fluid and emit it out into the enteron. The endoderm in the region of hypostome (manubrium) is particularly rich in gland cells.

The **mesogloea** is gelatinous and has muscle fibres at places but no cells. At some places, a continuous muscle layer is found. These muscle fibres appear to be greatly elongated cells and may be designated as *muscle-cells*. On both sides of mesogloea is found *probably, a nervenet*.

2. **Blastostyles** are elongated cylindrical bodies occurring in the proximal regions of the colony. The transparent chitinous investment in which the blastostyle is encased is known as *gonotheca*. The *blastostyle* is really a modified polyp and is found in the axil between the *hydrocaulus* and the hydranth. At the distal end of the gonotheca develops an opening which remains closed by a lid. The blastostyle is a *zooid* and has *neither mouth nor tentacles*. The *coenosarc* of the blastostyle proliferates to form the medusae which are released on becoming mature. The central

axis is known as the *blastostyle* which along with gonotheca is called the *gonangium*; the lateral buds are the *gonophores* which develop into medusae. The gastrovascular cavity, tentacles and mouth are all reduced in the blastostyle.

3. The **medusa**, the third type of zooid is the sexual zooid and bears gonads differing in this respect from the polyp as well as the blastostyle. The medusa is saucer-shaped or bell-shaped. When the *medusae*, developed as buds from the blastostyle, become mature, they get detached and are released through the gonothecal pore. Thus released, the medusae freely swim about in open sea.

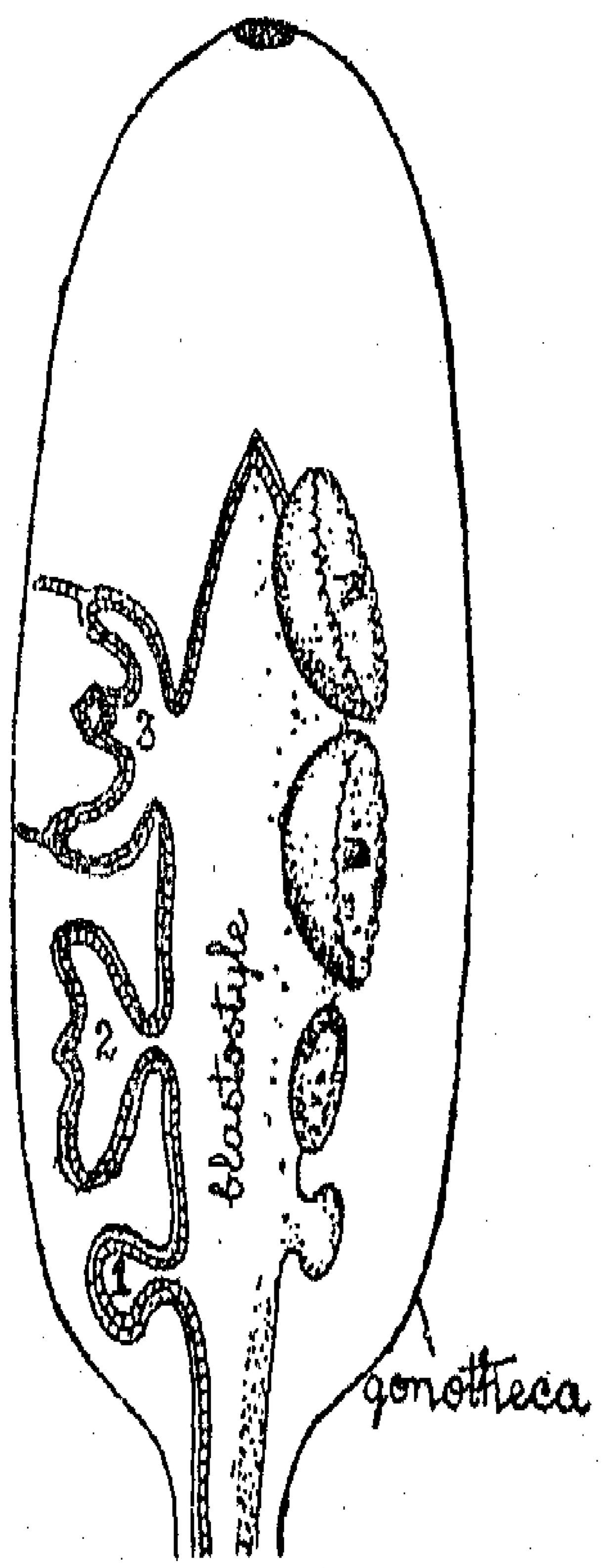

Fig. 115. Diagram showing the development of medusa from the blastostyle; 1, 2, 3, show successive stages; on one side are shown fully developed medusae (Diagrammatic).

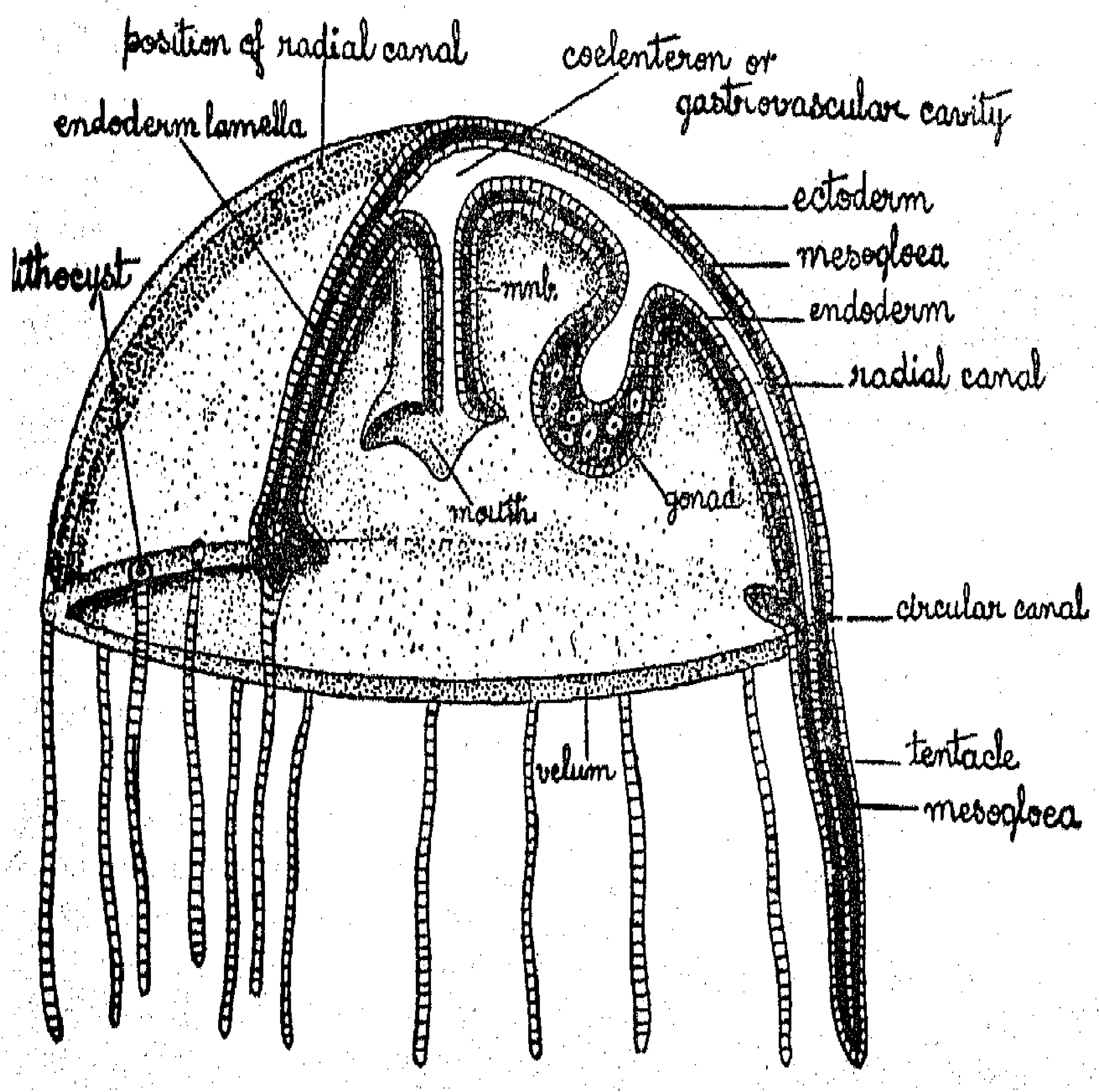

Fig. 116. A diagrammatic representation of the structure of medusa of Obelia. A quarter of the medusa has been cut away (After Parker and Haswell).

The concave inner surface of medusa is called the **subumbrella** and the convex outer surface is known as the **ex-umbrella.** From the middle of the concave surface of medusa arises the *manubrium* bearing a quadrangular *mouth opening* at its summit. At its rim, the young medusa bears sixteen tentacles; their number increases with the age of medusa. In the normal position the medusa swims with its convex surface directed upwards; the mouth opening leads by a passage through the manubrium into a cavity called *enteron.* From the dilated base of the enteron, which lies in the central apical region of the convex bell, arise *four radial canals* each being *per-radial* in position and each proceeding through the gelatinous substance of the medusa, towards its rim. Along the rim of the bell, through the substance of the medusa runs a *circular canal* or a *ring canal.* Each radial canal opens into the circular canal. The dilated basal part of the enteron (or the stomach), the four radial canals, the circular canals and the manubrium: all these constitute a continuous 'gastrovascular system' of the medusa; the entire gastrovascular system is lined by endoderm.

The free-swimming medusa feeds through its mouth; it is carnivorous in habit and lives upon small organisms like crustaceans, annelid worms, nematodes, eggs and larvae etc. The digestion which is *partly extracellular and partly intracellular* occurs in the manubrium and the stomach and the digested food is distributed to the entire medusa by the 'canal system' in which the gastrovascular fluid naturally circulates.

The histological constitution of medusa is very much like that of the polyp: the same layers, the *ectoderm,* the *endoderm* and the intervening *mesogloea* being present. Both the exumbrellar and the subumbrellar surfaces of the medusa are covered over with ectoderm. (There is no chitinous investment or exoskeleton in medusa). The manubrium has in its walls, precisely the same arrangement of these layers as that obtained in case of the hydranth. In the substance of the medusa, between the radial canals, intervening between the exumbrellar and the subumbrellar ectoderm, there is found a thin sheet of endoderm known as the *endoderm lamella.* In all parts between the ectoderm, and the endoderm *mesogloea* is found.

Running along the marginal edge of the medusa is a weakly developed *velum*: a very narrow internal shelf of fold extending along the border of the subumbrellar cavity; the velum is composed of two layers of ectoderm and an intervening *mesogloea,* there being no endoderm extending into it.

Tentacles which arise from the velum have an endodermal axial core enveloped by ectoderm profusely armed with *nematocysts.* In the circumference of the medusa are found eight marginal *sense organs* or *statocysts,* one at the base of each adradial tentacle. The *statocyst* is a minute closed vesicle lined with sensory ectoderm and filled with a fluid in which is found one minute *particle* or *grain* of calcium carbonate known as *statolith*. The *statocyst* is able to perceive or detect the position of medusa while swimming and the zooid is able to bring its position to normal should it become tilted or bent. *The statocyst thus performs the important function of orientation. The statocyst also helps in the maintenance of normal swimming movements of medusa.*

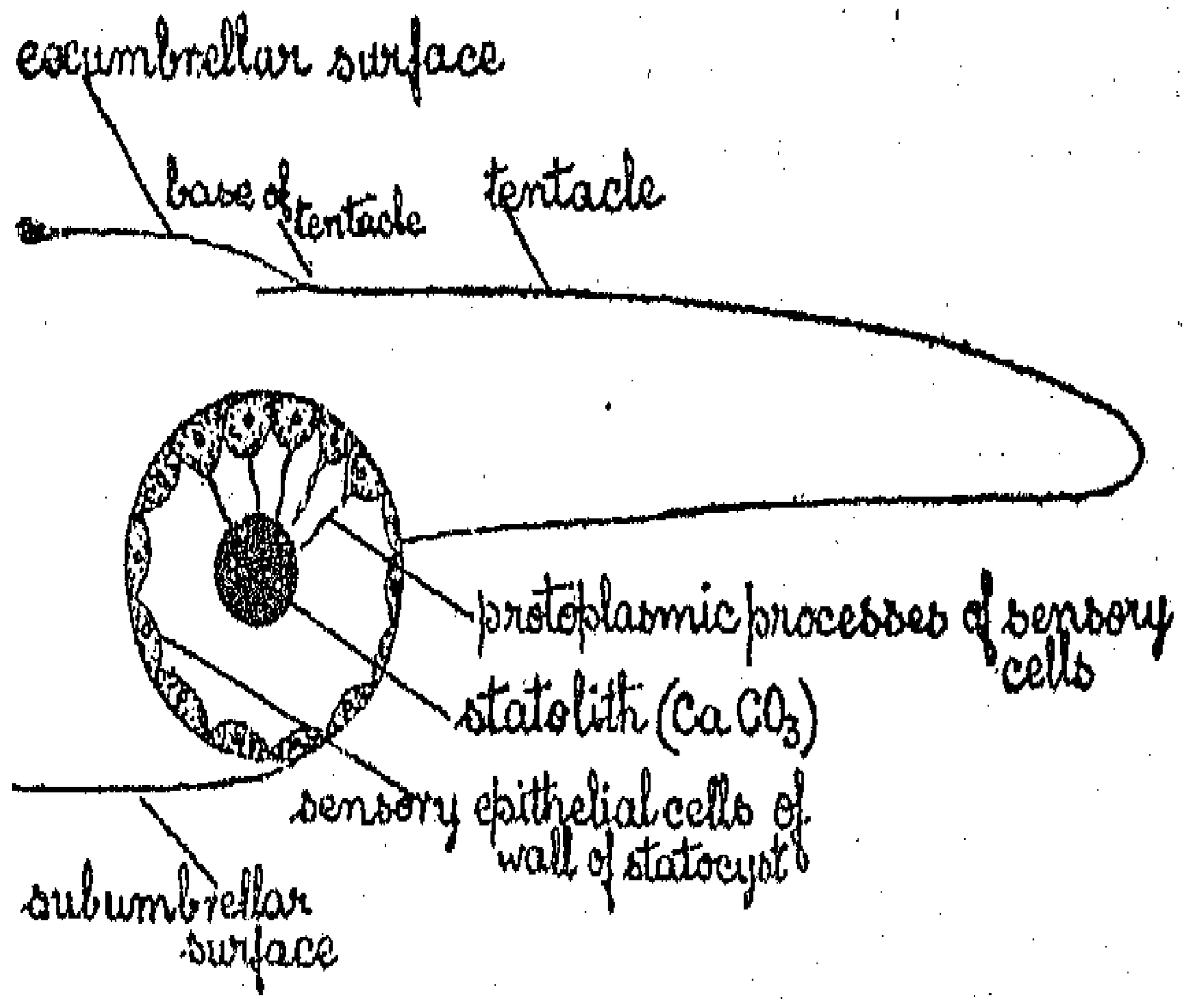
excumbrellar surface
base of tentacle
tentacle
protoplasmic processes of sensory cells
statolith (CaCO₃)
sensory epithelial cells of wall of statocyst
subumbrellar surface

Fig 117. Structure of statocyst shown diagrammatically.

The muscular system is well-developed on the subumbrellar surface and while swimming the medusa performs rythmic closing and opening movements of the bell. The subumbrellar muscle-cells and muscle-tails undergo rythmic contractions due to which the medusa keeps swimming normally.

The *medusae* are *dioecious* (unisexual). Each medusa has *four ovoidal gonads* on the subumbrellar side, one in the middle length of each radial canal. The gonads are per-radial in position. The *gonad* develops as an outpushing of the wall of radial canal and hence consists of *ectoderm, endoderm, mesogloea* and a *diverticulum* of the enteron. The reproductive cells are initially formed from the ectodermal cells of the manubrium but travelling along the radial canals they reach the ectoderm of the gonads. The ripe *ova* or flagellated *sperms* as the case may be are liberated into the sea due to the rupture of gonads. Cross fertilization occurs in open sea. The medusae swim about in open sea, detached from the parent colony and by sexual reproduction give rise to new colonies in fresh habitats away from the parent colony. Thus the medusa serves two important functions: (i) *sexual reproduction* and (ii) *dispersal of the species.*

With the assumption of a free-swimming life, medusa has developed certain features of necessity and advantage for such a life. All such features of medusa which have developed in correlation with its mode of life (free-swimming) and which are also of advantage to it in achieving its mission of life (sexual reproduction and dispersal) may be considered as its *adaptational features.*

The adaptational features of the medusa are: 1, For active dispersal, the medusa has assumed a free-swimming life; it feeds independently, ingests and digests food. 2, Muscular system is well developed for performing rythmic movements needed for swimming. 3, *Statocysts* are developed at the base of eight adradial tentacles. 4, Nervous system is well developed; the double nerve ring at the margin exercises a sort of central control on the movements of the whole organism. 5, Nematocysts are well distributed all over the body as well as in the ectoderm of tentacles; they are weapons of 'offence and defence' and keep the medusa 'secure' against enemies. 6, Mesogloea is much more developed (than other zooids) and it provides bulk and support to the medusa which lacks a chitinous exoskeleton.

Life-cycle: As a result of fertilization (already described) *zygote* is formed. The *cleavage is complete* and a *blastula* containing a single layer of cells (*ectoderm*) enclosing a central cavity, is

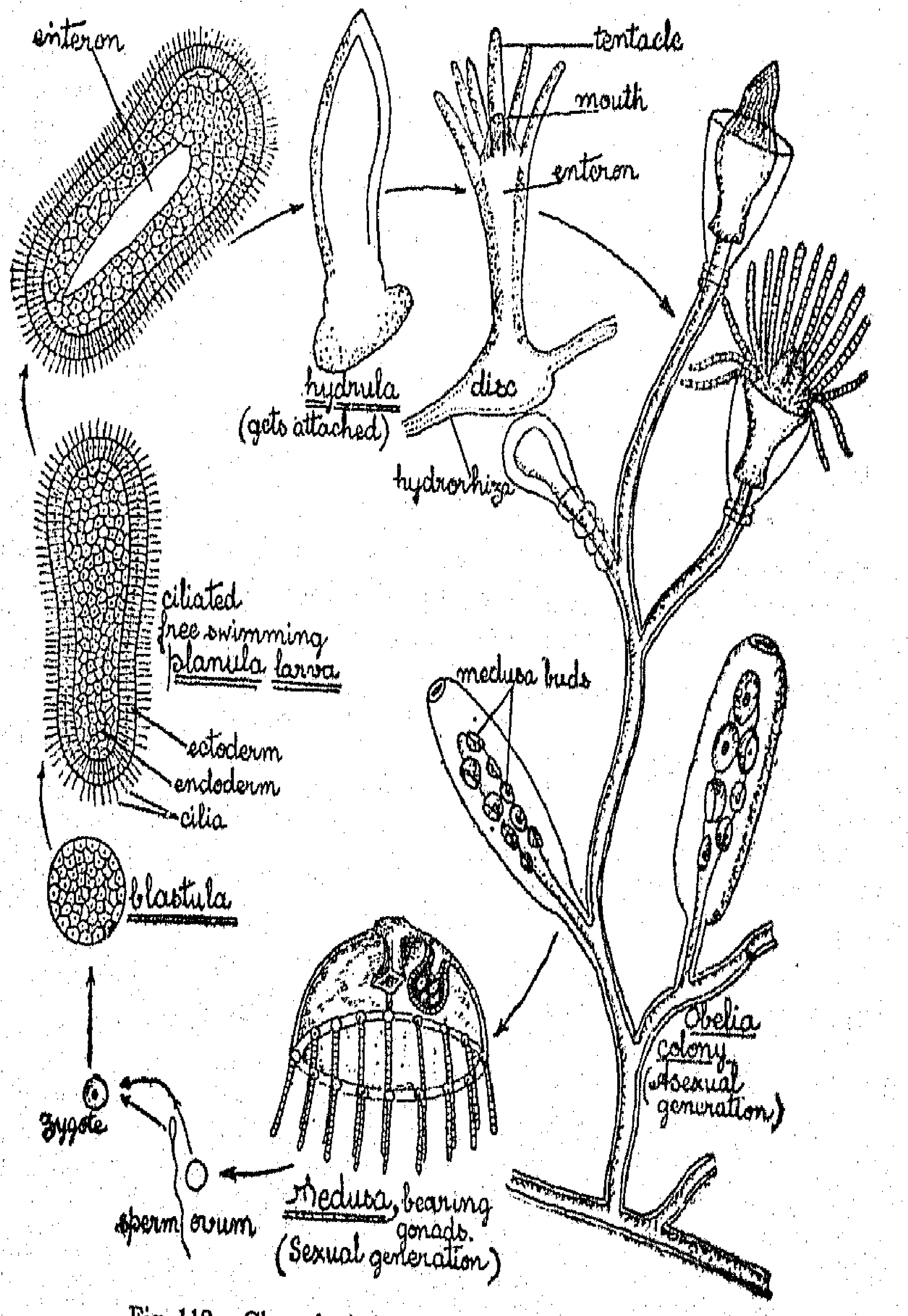

Fig. 118. Chart depicting the life-history of Obelia.

first formed. Cells budded off from the wall of the blastula migrate inwards and fill up its internal cavity; these cells filling up the cavity form the *endoderm.* The outer ectoderm becomes ciliated. This ciliated larval stage containing a solid core of endoderm is known as *planula. Planula* swims about freely and brings about wide dispersal of the species as it drifts along the currents to distant places.

A split or delamination soon occurs in the endoderm of the planula in an antero-posterior direction as a result of which a cavity called *enteron* is formed in the interior of the larva. The planula now settles down in a vertical position and gets attached by one end to some substratum: some rock, piece of timber, sea-weeds etc. At the opposite end, a *mouth* develops.

The basal part of the attached larva becomes thick and at this end a *disc of attachment* is formed in a horizontal position. At the distal end, a *manubrium* and a *circlet of tentacles* develop; now the stage which resembles a polyp is known as *hydrula.*

Lateral buds and branches arise from the hydrula, particularly from the disc of attachment in a direction horizontal to that of substratum. These horizontal branches form the *hydrorhiza* from which vertical branches known as *hydrocauli* arise. This branching system forms into a cymose pattern and bud-like enlargements are formed at the terminal ends of the lateral branches; these buds develop into polypes. In the proximal region of the colony, in the axil of the polyps develop the buds which form *blastostyles.* Ultimately, starting from the hydrula, by repeated branching and budding, the adult *Obelia* colony is formed.

Alternation of generations[1]: *Obelia* in course of its life history passes through two distinct phases: (i) the sex-less or the asexual *Obelia colony* which reproduces asexually by budding and (ii) the *medusa* which bears gonads and reproduces sexually. These two generations alternate and thus we have in *Obelia,* alternation of an asexual generation, the *Obelia colony* with a sexual generation, the *medusa.* [In true alternation of generations, the asexual generation is diploid and the sexual generation is haploid.] In case of *Obelia,* however, both the generations are diploid i. e. the chromosome number in medusa is not half of that of *Obelia* colony. The number of chromosomes in the constituent body cells of both the generations is 2*x*. According to many, therefore, true alternation of generations does not occur in *Obelia*; they are of opinion that the case of *Obelia* is a case of **Polymorphism.**

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[1] [*Obelia* shows a special kind of alternation of generations known as **metagenesis.** In case of metagenesis, alternation occurs of a generation which reproduces only asexually by division or budding with a generation which reproduces only sexually by means of ova and spermatozoa. The *Obelia colony* reproduces asexually forming buds of two kinds: hydranths or *polypes* and *gonangia*; the sexual generation is represented by *medusae.*]

Comparison of the polyp of Obelia with its medusa: homology of the two: Despite the striking differences from each other, the polyp and medusa are strictly *homologous*[1] and the structurally elaborate medusa can be *theoretically* derived from the simple polyp. The base of the *polyp* corresponds to the apex of the *medusa* and the manubrium of the polyp precisely corresponds to the manubrium of the medusa.

If the tentacular part of the hydranth is pulled out into a disc which is then curved into a saucer-like form with its concavity on the oral side, a medusa like structure will result; the enteric cavity of this saucer shaped zooid will become narrow due to proximation of the oral and aboral body walls and thus the bell-like structure will come to have a double wall: the enteric cavity

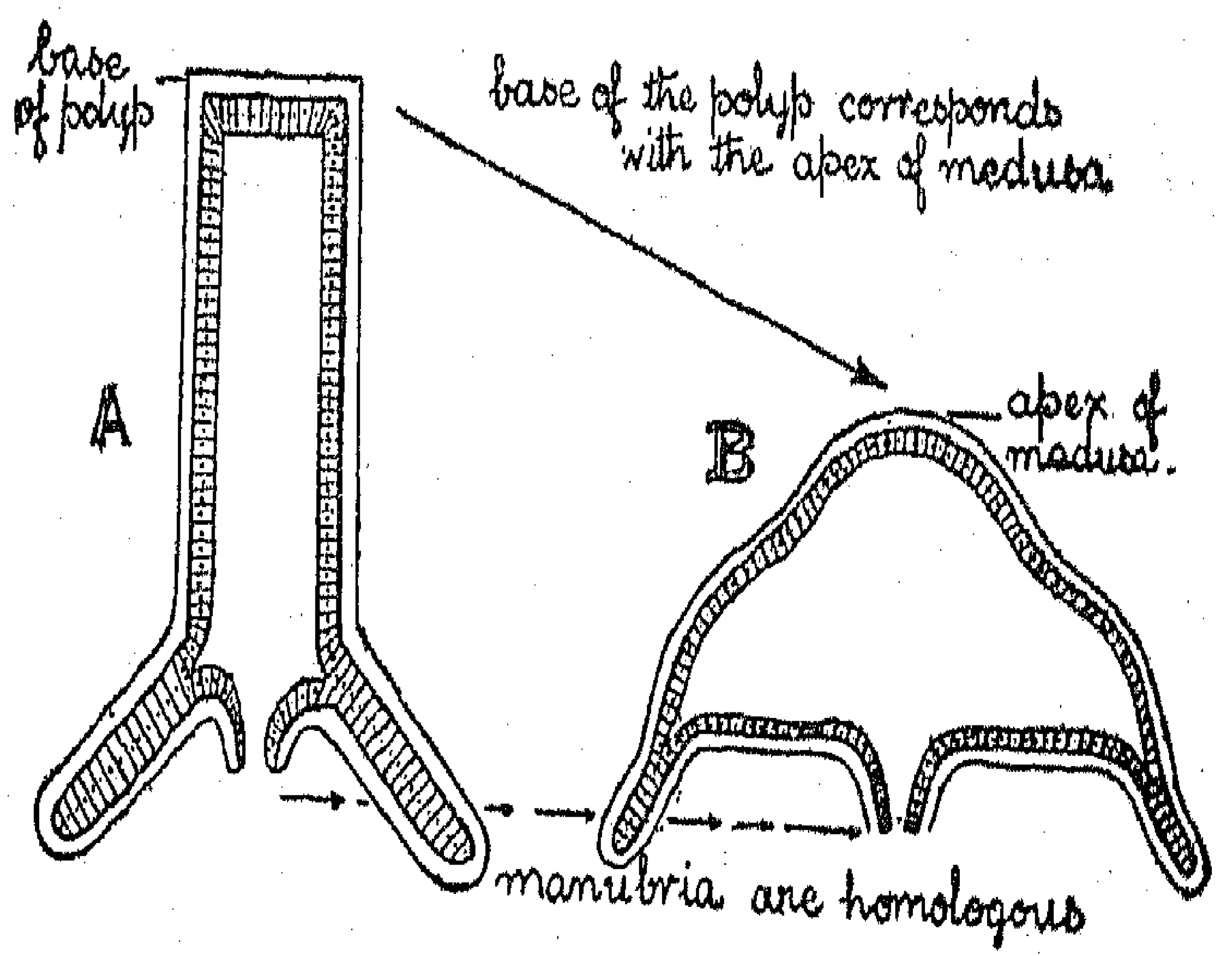

Fig. 119. Diagram showing the homology of the polyp and medusa A, polyp ; B, medusa derived from polyp.

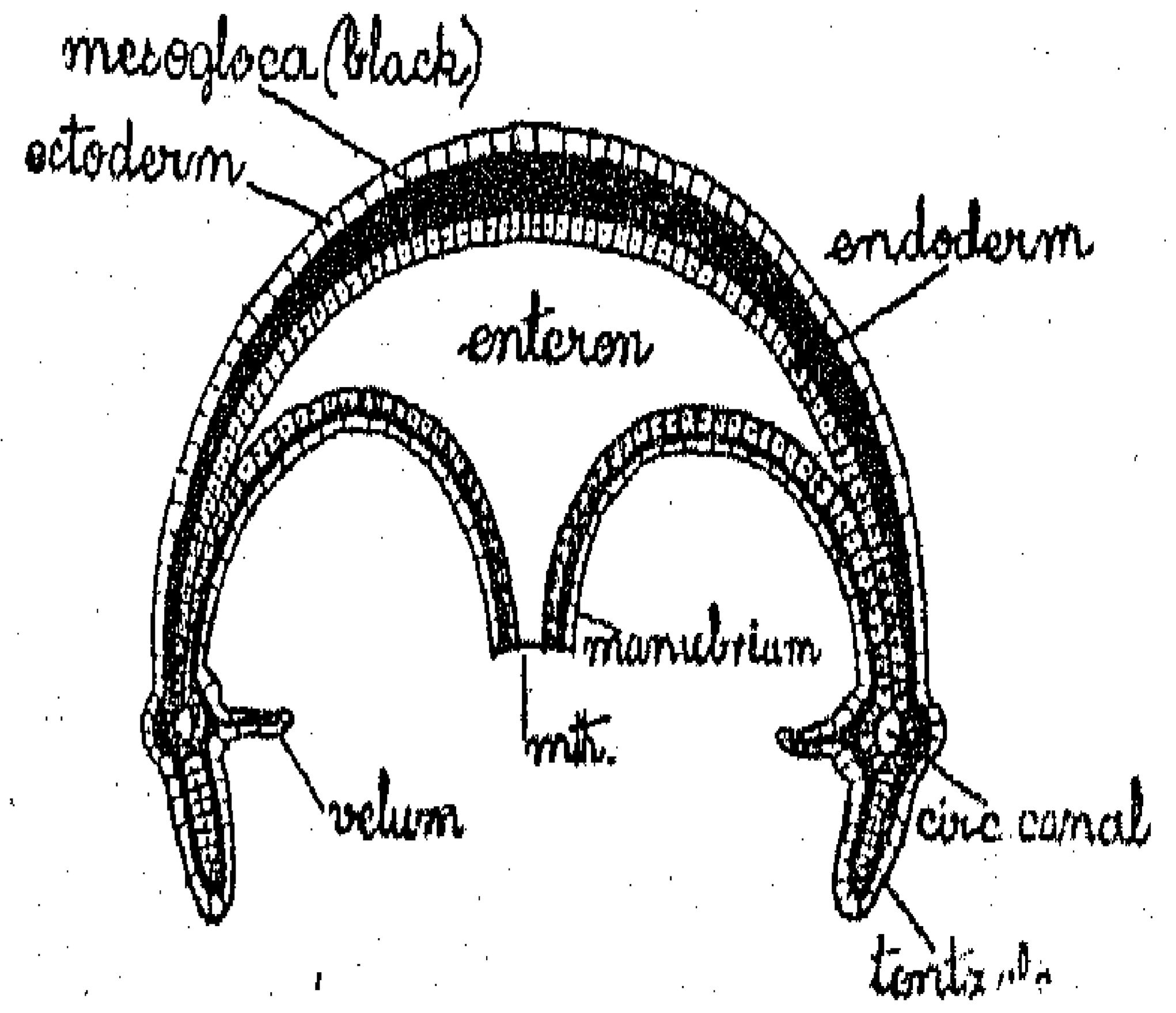

Fig. 120. Medusa derived from polyp.

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[1] [Structures which have the same origin and structure and which are therefore morphologically equivalent are spoken of as homologous structures.]

will be lined with *endoderm* and the entire surface will be covered over by the *ectoderm*. The endoderm layers of the exumbrellar and subumbrellar body walls fuse due to growth of mesogloea of the exumbrellar body wall ; as a result the *endoderm lamella* is formed. The two endoderm layers do not fuse (i) along the four per radii along which the four radial canals are developed and (ii) a circular area close to the marginal edge which forms the circular canal.

1. Comparison of Polyp and Medusa of Obelia

Polyp or hydranth	Medusa
1. Somewhat cylindrical in shape.	1. Saucer or bell-shaped.
2. *Hydrotheca* present (exoskeleton).	2. No such chitinous investment found.
3. Sedentary.	3. Free-swimming.
4. No sense organs found.	4. Special sense organs : *statocysts* found.
5. Sexless.	5. Is male or female ; bears gonads.
6. Muscular system less developed.	6. Muscular system is better developed.
7. Nervous system weakly developed. No nerve ring is found.	7. Nervous system is better developed which consists of a nerve-net on either side of mesogloea and a double nerve-ring along the rim.
8. *Enteron*, simple ; no canal system.	8. *Enteron*, complicated : canal system : *four radial* canals and a *circular canal* besides stomach are present.
9. Mesogloea less developed.	9. Mesogloea better developed than polyp.
10. No endoderm lamella found.	10. Endoderm lamella present as a thin sheet of endoderm between the exumbrellar and the subumbrellar surfaces, between the adjacent radial canals and between the circular canal and the enteron.
11. Independent feeding habit, carnivorous ; small crustaceans, nematodes, worms, aquatic larvae etc., are ingested. The prey is captured by tentacles and ingested by mouth opening.	11. The medusa also feeds independently and is carnivorous. The food is like that of polyp and is captured similarly.
12. The manubrium is *conical*, hollow, encloses a portion of enteron. Its wall consists of an outer layer of *ectoderm*, an inner layer of *endoderm* and an intervening layer of *mesogloea*.	12. The hollow manubrium is quadrangular and bears at its apex a four-sided mouth, it encloses a portion of enteron, its wall also has *ectoderm*, *endoderm* and *mesogloea*.
13. The tentacles are formed of a core of endoderm covered over by ectoderm particularly rich in nematocysts. The tentacles are food-capturing organs.	13. The tentacles are solid like those of polyp and consist of a core of endoderm enveloped by ectoderm richly supplied with nematocysts. The tentacles are food-capturing organs.
14. The ectoderm, mesogloea and the endoderm constitute the body wall. The enteron is digestive and absorptive and is lined by endoderm.	14. The ectoderm, mesogloea and the endoderm constitute the body wall. The enteron is digestive and absorptive and is lined by endoderm.
15. The base of the polyp corresponds to the apex of the bell or medusa.	15. The apex of the medusa is homologous with the base of the polyp.
16. The mouth and manubrium of the polyp are homologous to the mouth and manubrium of medusa respectively.	16. The mouth and manubrium of the medusa are homologous to those of the polyp.
17. Digestion is partly extracellular and partly intracellular.	17. Digestion is partly extracellular and partly intracellular.
18. The polyp is radially symmetrical.	18. The radial symmetry is more pronounced due to the development of radial canals.

28

Structure and Life-history of Aurelia Comparison with Obelia

1. **Compare and contrast the life-histories of Aurelia and Obelia.** (L. U. B. Sc. Pass, 1948)

2. **Give an account of the structure of Aurelia. How does Aurelia differ from the medusa of Obelia.** (L. U. B. Sc. Pass, 1953)

3. **Describe the life-history of Aurelia.** (L. U. B. Sc. Pass, 1960)

[*Aurelia* belongs to the class **Scyphozoa** which is a group of medusoid coelenterata with no or inconspicuous polyp stage; polyp when present forms medusae by transverse fission; velum, nerve-ring and skeleton are absent; gonads are endodermal. Under this class *Aurelia* belongs to the Subclass—Discomedusae, order Semaeostomeae. **Discomedusae** include free-living medusae, sessile only in the larval stage. Order Semaeostomeae includes medusae lacking septa and gastric pouches in the adult.]

Aurelia aurita is a common British jelly-fish although it is of world-wide distribution; it inhabits coastal regions of sea and its body is a gelatinous saucer shaped umbrella of about 1·5 to 2 inches radius. The gelatinous umbrella like body is concave convex; the convex or the exumbrellar surface remains directed upwards and the concave or the subumbrellar surface remains directed downwards in the normal swimming position. The rim of the umbrella is incomplete at eight places of which four are per-radial and four are inter-radial in position. In each of these eight notches lies a pair of marginal lappets. In each notch, hidden between the marginal lappets lies the *tentaculocyst*, a sense organ concerned with the initiation and control of the rythmic swimming movements of *Aurelia*. The entire edge of the umbrella, save the eight recesses in the eight marginal notches, is fringed by close-set marginal tentacles which are short but very numerous. The thin and narrow edge along the rim of umbrella, the marginal notches and the fringe of the marginal tentacles constitute the **velarium** which contains endodermal canals, differing in this respect from the velum of the *obelian medusa*.

The short and inconspicuous *manubrium* arises from the centre of the subumbrellar surface and bears at its summit a four sided

mouth opening. Each of the four corners of the mouth is drawn into an *oral arm* which is broad at its junction with the mouth and tapers to a narrow end. Towards their inner side; the four oral arms unite around the mouth. Each arm as well as the four corners of the mouth are per-radial in position. Each oral arm is grooved on the subumbrellar side, the groove runs lengthwise along the arm and extends from the narrow outer end of the arm towards the corresponding angle of the mouth. The grooves which are ciliated and lead into the gullet act as exhalant pathways for the circulating fluid of the gastrovascular system. Each oral groove runs between two longitudinal and convoluted ridges which are richly supplied with nematocysts.

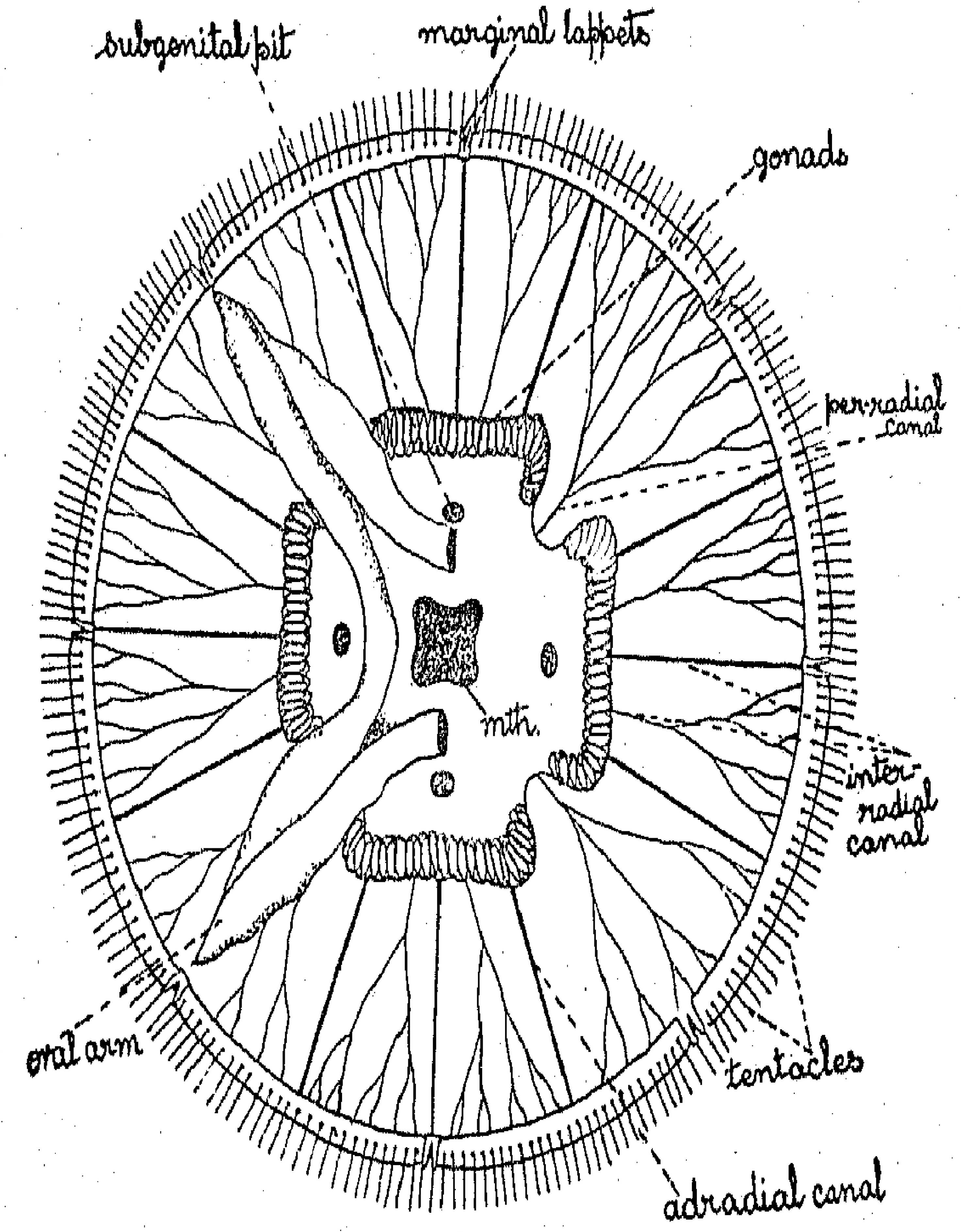


Fig. 121. Aurelia, with two oral arms removed. (Oral view).

An elaborate digestive and canal system or the **gastrovascular system** consisting of *mouth, gullet, stomach, gastric pouches, radial* and *circular canals* is found in *Aurelia*. The system performs ingestion, digestion, absorption as well as distribution and circulation of nutrition (and possibly of oxygen also). This system is physiologically more advanced than that of the medusa of *Obelia* in the fact that here (in *Aurelia*) *the circulation of fluid occurs in definite directions due to the action of cilia of the lining epithelium.*

The stomach and the canal system are lined by the endoderm and the entire system is ciliated.

The *mouth* leads into a short *gullet* which passes through the manubrium ; the gullet opens into a spacious endodermal stomach which lies in the central part of the animal. From the central stomach; in between the adjacent oral arms and therefore inter-radially in position, arise (one in each inter-radius) four *gastric pouches* each extending nearly mid-way from the centre to the periphery. Between the adjacent gastric pouches intervenes thick jelly. Three apertures are found in the outer wall of each gastric pouch ; from each of these apertures a radial canal arises. The canal arising from the middle aperture is *inter-radial* while from each of the other two apertures arises an *adradial canal.* In each of the four re-entering angles between adjacent gastric pouches, there is an aperture from which arises a *pre-radial canal* : thus there are *four per-radial canals, four inter-radial canals* and *eight adradial canals* ; in all there are sixteen of these radial canals which arise from the *central gastric cavity* and run radially to open into the narrow *circular canal.* Of these, the eight adradial canals are unbranched. Each of the per-radial and inter-radial canals branches

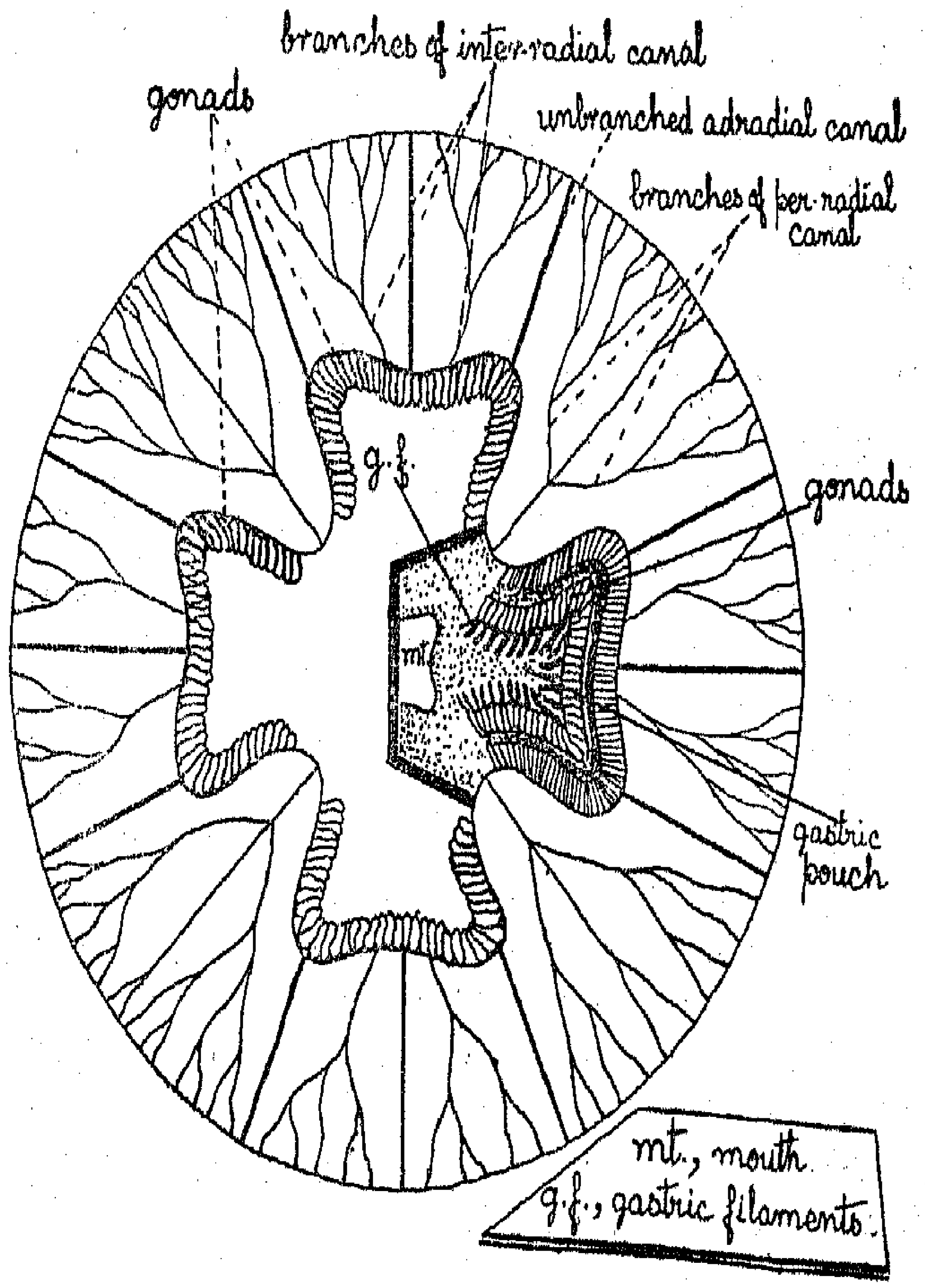

branches of inter-radial canal
gonads
unbranched adradial canal
branches of per-radial canal
g.f.
mt
gonads
gastric pouch
mt., mouth
g.f., gastric filaments

Fig. 122. Aboral view of Aurelia : a portion of umbrella has been removed exposing one gastric pouch ; the gastric filaments are visible. (Based on Parker and Haswell).

into three and each of these three divisions branches again. The eight unbranched adradial canals alternate with the branched radial canals.

Lying on the floor of each gastric pouch and curved in the form of a horse-shoe with its concave surface towards the mouth is a frill-like endodermal *gonad* originating from the floor of the gastric cavity (the *enteron*). There are in all four gonads, all *inter-radial in position. Aurelia* is unisexual, it may be male or female.

A row of delicate endodermal **gastric filaments** or **phacellae** lies parallel to the inner border of the gonads ; these project freely into the lumen of the gastric pouch. Each gastric filament has structurally a core of mesogloea and an endodermal covering :

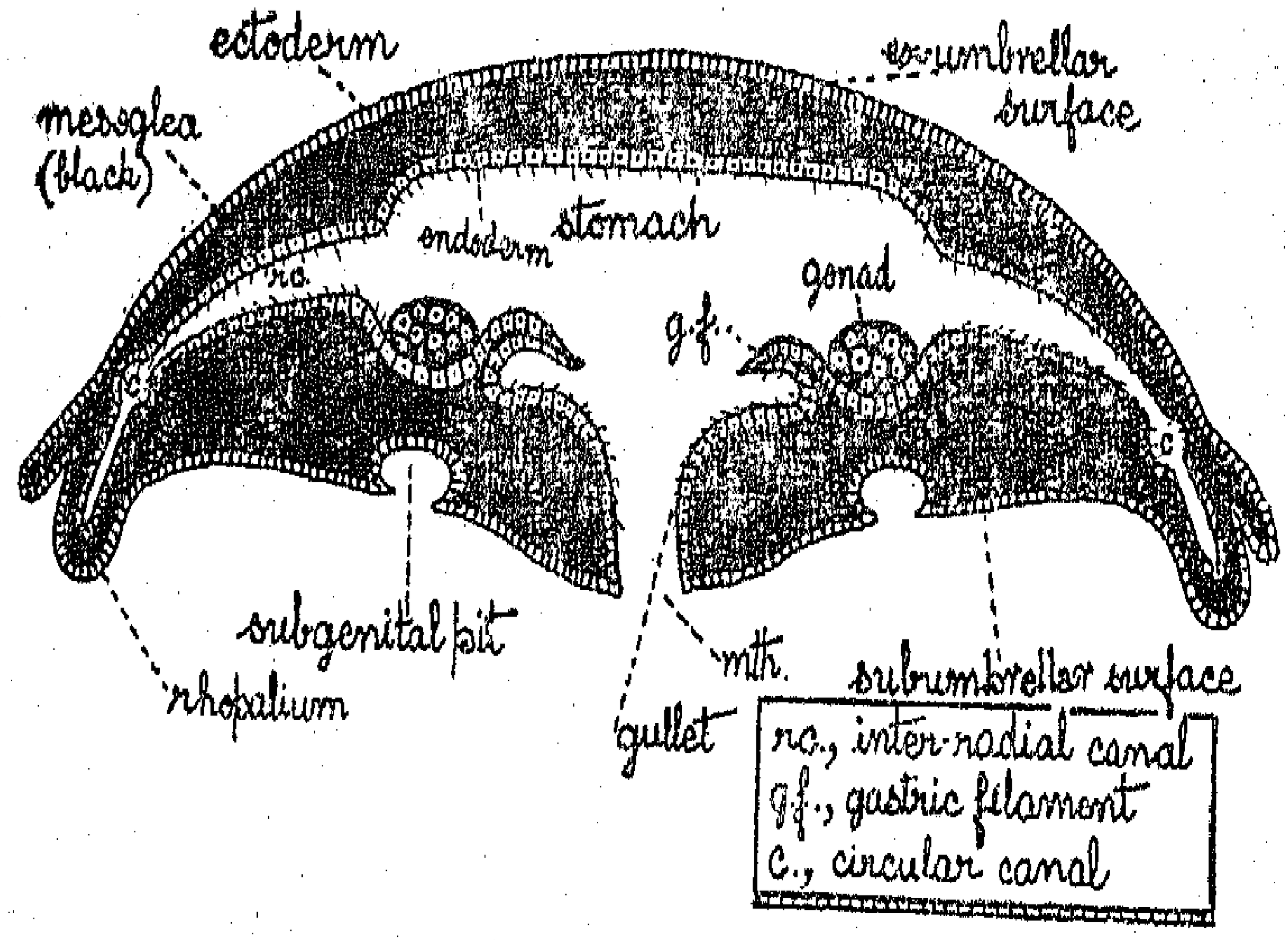


Fig. 123. A vertical section through Aurelia showing the position and relation of important parts (Diagrammatic).

the endodermal cells contain batteries of nematocysts which kill preys taken into the stomach. Digestion is partly extracellular and partly intracellular. *Aurelia* is carnivorous and feeds on small aquatic animals, small invertebrates etc. Most of the food is digested in stomach ; the remaining part which consists of very small particles is digested and absorbed in canals. Maximum absorption occurs in the canals which reach all parts of the body.

Cell-layers in the body.—The *mesogloea* is thick and gelatinous and forms the main bulk of the body ; it contains distinct amoeboid cells and certain branched fibres. Both the exumbrellar and the subumbrellar surfaces are covered over by the *ectoderm* while the stomach and the canals are lined by *ciliated endoderm.*

Muscular and nervous systems, sense organs.—The contractions of the body by which *Aurelia* 'swims' are effected by the rythmic contractions of the elongated muscle fibres (modified ectoderm cells) disposed in a circular fashion on the peripheral regions of the subumbrella where they form a muscular zone round the subumbrellar edge. The *nervous system* is confined to ectoderm and consists of a nerve net extending over the subumbrellar surface between the superficial epithelial layer of ectoderm and the muscular layer. The nerve net (plexus of simple nerve-fibres) has particular concentrations near the tentaculocysts and radial thickening in the per-and inter-radii. Round the rim, near the circular canal is found a ring like nervous concentration.

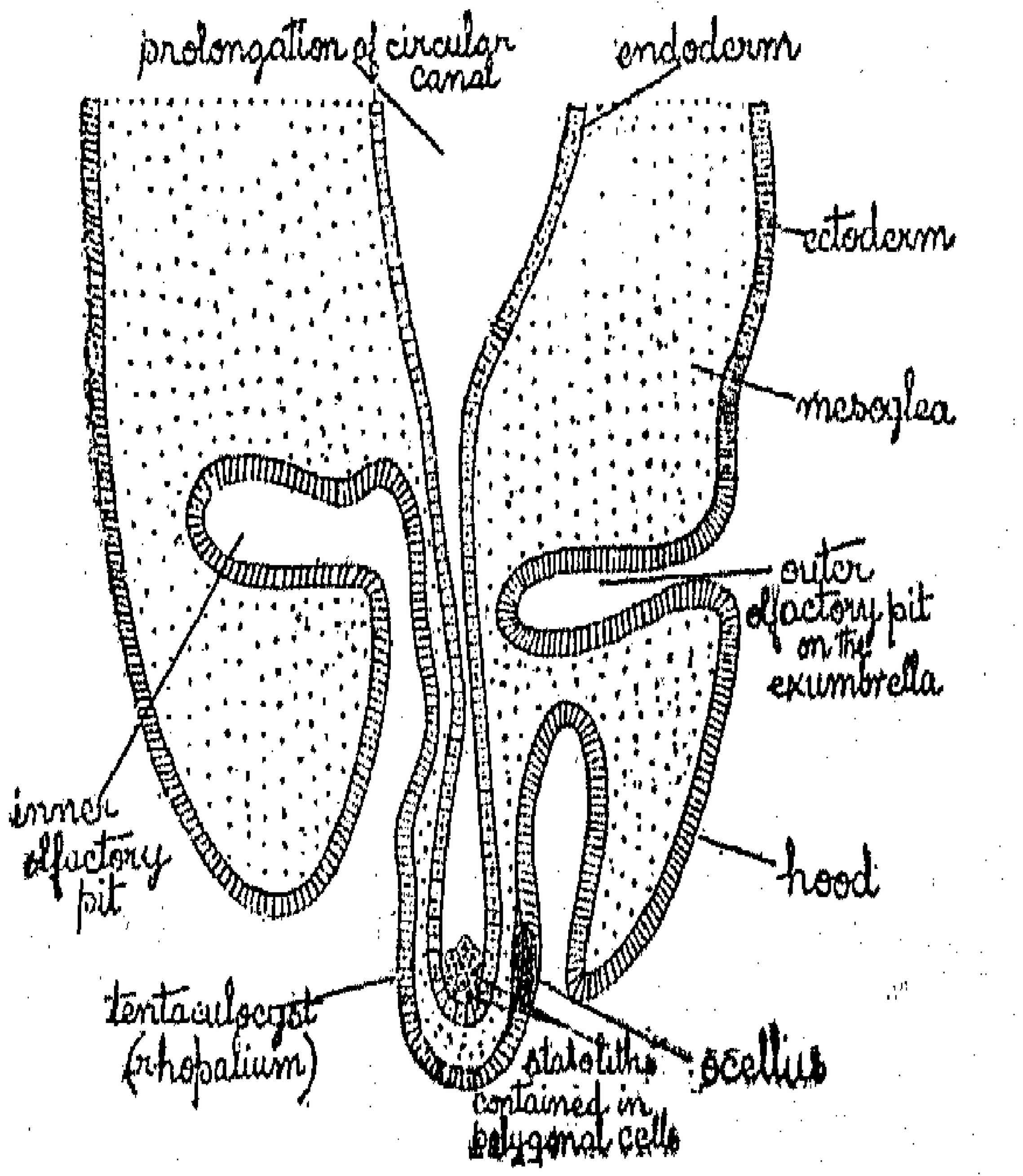

prolongation of circular canal
endoderm
ectoderm
mesoglea
outer olfactory pit on the exumbrella
hood
inner olfactory pit
tentaculocyst (rhopalium)
statoliths contained in polygonal cells
ocellus

Fig. 124. Vertical section through rhopalium etc. of Aurelia (Diagrammatic.)

Rhopalium (or the tentaculocyst): In each of the eight marginal notches, a gravity-perceptive sense organ or *rhopalium* is found which is largely hidden by the **marginal lappets** and a flap or hood like process connecting them. Each rhopalium is a *hollow sense-club*, the **tentaculocyst** which contains a prolongation of the circular canal; at its free dilated end are found calcareous concretions known as **statoliths** (formed of calcium phosphate, oxalate and sulphate). The edge of the umbrella projects over the rhopalium as a hood. On one side of the tentaculocyst is a light perceiving ectodermal red pigment spot or **ocellus**. The umbrella moves more fastly if light falls upon it. The two *olfactory pits* (one on the exumbrellar surface and one immediately internal to the hollow sense-club; see fig. no. 124) are lined with sensory epithelium. Immediately beneath the sense-club, a pad of sensory epithelium is found on which the sense-club of the highest tentaculocyst will press more strongly should the umbrella be tilted from its normal horizontal position. Due to this, the tentaculocyst of the raised side of umbrella produces stimulation and the animal becomes conscious of its position and contracts its muscles and restores its normal position for which the animal has a well-developed 'righting reflex'.

The tentaculocysts perform two functions: (i) *initiation and control of rythmic swimming* movements and (ii) *gravity-perception* due to which the animal is able to right its position if tilted.

Reproduction and Development: Life-cycle, *Aurelia* is unisexual, either *ova* or *sperms* are produced in a particular individual. The gonads are developed from the floor of the enteron and hence they are endodermal in nature. The germ cells: *ova* and *sperms* are discharged into the gastric cavity wherefrom they find their way to the exterior via gullet and the mouth. The sperms reach with water-current to the ova lodged in the gastric pouch where fertilization occurs. The fertilized eggs travel through the canals to the openings on the oral arms; the egg undergoes its early development in the pouches at the sides of the oral groove. Minute **planula larvae** are often found along the side of the lips of the oral grooves.

The fertilized ovum undergoes cleavage, dividing regularly and forms a **morula**, a mass of cells. In the interior of the morula, fluid accumulates as a result of which a single-layered closed sac-like embryo called blastula is formed. The blastula encloses a cavity. *Invagination* occurs at one end of the blastula converting it into a **gastrula.** The mouth of the gastrula (formed by invagination) or the blastopore becomes narrow but does not close. The embryo is now *two-layered* consisting of an outer **ectoderm** and an inner **endoderm.** Cilia develop on the ectodermal cells. This two-layered elongated ciliated embryo is called a **planula larva**; it is set free from the oral groove and starts an active free-swimming life which lasts for a brief period.

Shortly, the planula loses cilia and gets attached by one pole to substratum; at the opposite free-end, a **mouth** develops. This attached polyp-like embryo is known as **hydra-tuba** (It has no perisarc). Round the mouth (in stages) of the hydra-tuba, sixteen slender *tentacles* (4 per radial, 4 inter-radial and 8 ad-radial) develop. The proximal end of the hydra-tuba becomes narrowed. Collenchyma develops in between the ectodermal and the endodermal layers. The cavity inside, lined by endoderm is the *enteric cavity*. The mouth opening is four-sided and a *manubrium* is formed. At the base of the hydra-tuba develops a horizontal stolon from which fresh hydra-tubae may be produced by budding. Four longitudinal ridges in the endoderm known as **gastric ridges** or **taenioles** are formed one in each inter-radius and each projects into the enteric cavity. The distal body wall round the *mouth*, between the mouth opening and the whorl of tentacles gets invaginated in each inter-radius: these invaginations become further depressed into four **septal funnels** or **infundibula** which extend from above, below in the body of the animal. The septal funnels sink in the gastric ridges one in each gastric ridge.

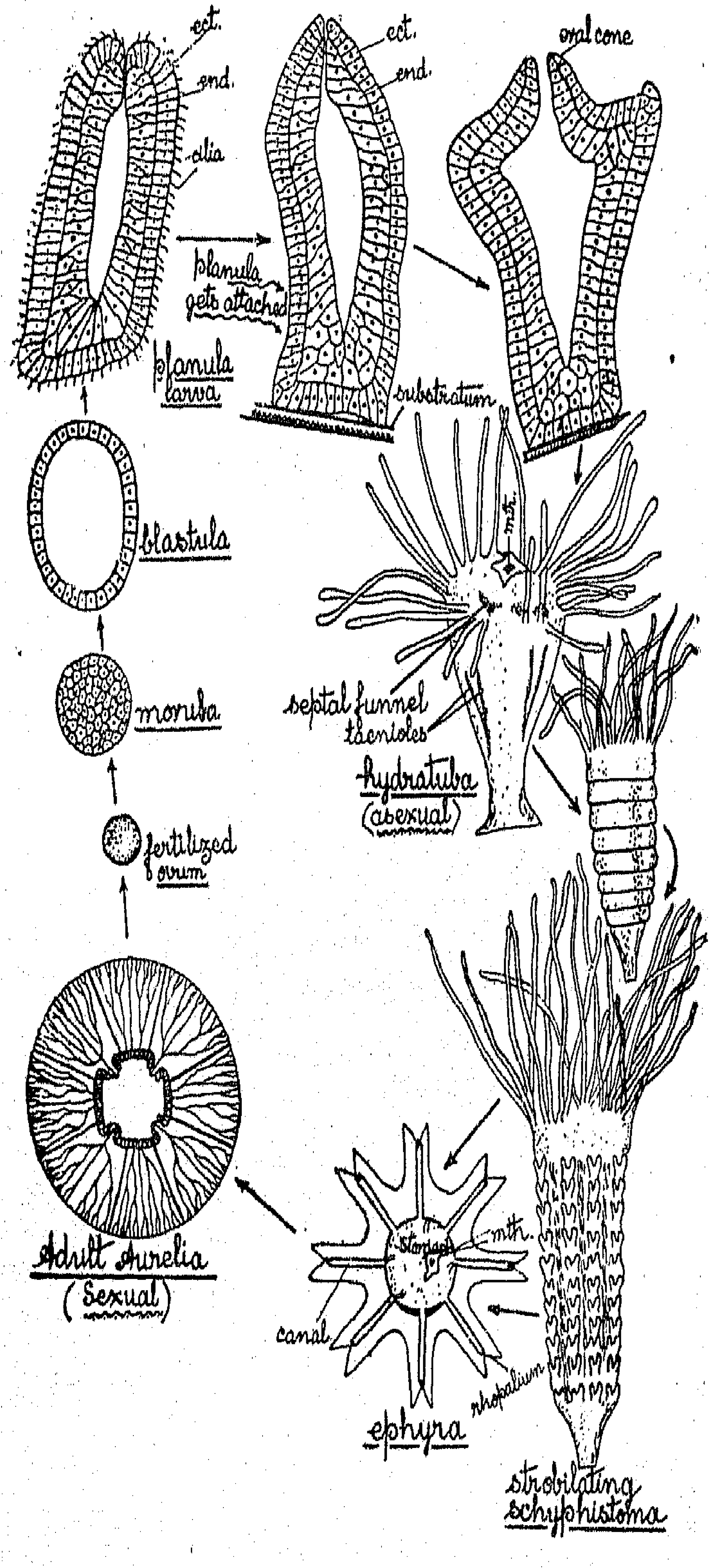


Fig. 125. Life-cycle of Aurelia (Schematic).

The hydra-tuba now undergoes *transverse fission*, simultaneously in a number of transverse planes as a result of which the body becomes divided into a number of disc-like segments lying upon each other as a pile of saucers connected together by strands of tissue. The process of transverse fission is known as **strobilation** and the segmented hydra-tuba is known as **scyphistoma.** The inter-radial strands of muscles which till now kept the 'saucers' bound together, break, setting free these saucers, now called *ephyrula* or *ephyra larvae.*

Each **ephyrula** is a disc like structure having eight long bifid arms four of which are per-radial and four are inter-radial. Its adradial regions are deeply notched. There is present in each ephyra, a segment of the stomach with a portion of gastric ridges; the gastric cavity becomes closed on the exumbrellar side. The ephyra contains the germ of all elements of the adult *Aurelia.* At the subumbrellar side, the gastric cavity remains open and develops a manubrium by the growth of its margins.

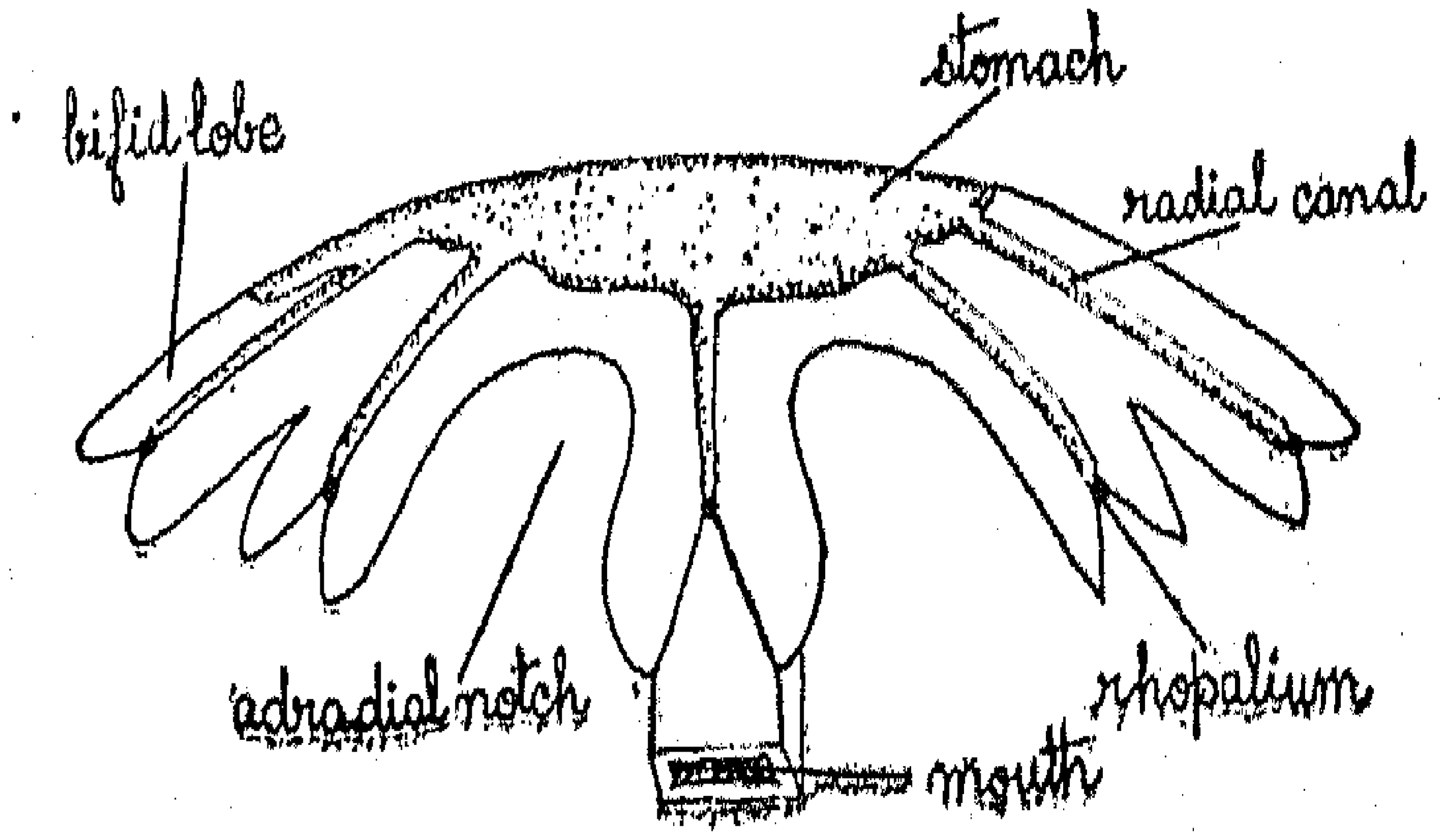


Fig. 126. The ephyra of Aurelia.

First, a single gastric filament grows on each gastric ridge and then a number of them appear. *Rhopalia* develop in the notches at the ends of the eight bifid arms. Marginal lappets etc. develop. The gastric cavity gives out canals which eventually branch and assume the adult form. The deep notches in the adradii between the eight bifid lobes are filled up by growth and the star-shaped ephyra becomes a circular disc with eight breaks in the circular edge lodging the rhopalia. Four oral arms develop and marginal tentacles develop. *Mesogloea* increases in thickness and as a result, two layers of the *endoderm* come together and form the *solid endoderm lamella* except in the region of canals. Now the adult Aurelia is formed from each of the ephyrulae.

The basal part of the strobilating scyphistoma (that which is left after the ephyrulae swim away) develops fresh tentacles; after a period of feeding and growth, it strobilates again and produces more ephyrulae.

Alternation of generations in Aurelia : The adult *Aurelia* which bears gonads represents the *sexual generation.* The **scyphistoma** can be taken to represent the *asexual generation* because the scyphistoma reproduces asexually by strobilation. The **asexual**

generation represented by the *scyphistoma* is a developmental stage in the life-history. The scyphistoma produces asexually by strobilation the *ephyrae* which metamorphose into adults of *Aurelia* (sexual generation).

The life-history of *Aurelia*, in fact presents a **case of metamorphosis complicated by multiplication in the larval stage** (i. e. scyphistoma). True alternation of generations may not be regarded as occurring in *Aurelia* because the asexual generation (scyphistoma) is only a developmental stage.

Comparison of Aurelia with the medusa of Obelia

I. Aurelia	II. Medusa of Obelia
1. The gonads are *endodermal*; the generative products are discharged into the gastric cavity wherefrom they pass out through mouth.	1. The generative products are located in *ectoderm* and are discharged directly to the exterior and not via gastric cavity.
2. Four inter-radial gastric pouches are found.	2. Gastric pouches are not found.
3. Four per-radial oral arms are found.	3. Oral arms are not found.
4. Endodermal nematocyst bearing *gastric-filaments* or *phacellae* are found in gastric pouches.	4. No gastric filaments are found.
5. The canal system is *elaborate* and there are in all sixteen radial canals; excepting the 8 adradials, 4 per-radial and 4 inter-radial canals are branched.	5. Only four per-radial canals are found. These are all unbranched. The canal system is simple.
6. No true velum is found; instead a *velarium* (formed of a very thin and the flexible narrow edge of umbrella with its marginal notches and the fringe of tentacles) is found which contains endodermal canals.	6. The *velum* is weakly developed: it consists of a double layer of ectoderm and the intervening mesogloea; no endoderm is found in it.
7. The marginal outline is *broken* at eight notches.	7. The outline of the umbrella is *unbroken* or entire.
8. Four per-radial and four inter-radial in position : in each of these eight notches are found a *rhopolium* (sense organ for gravity perception and control of swimming movements) an *ocellus* and two *olfactory pits*.	8. Rhopalia, ocelli and olfactory pits are not found. At the base of eight adradial tentacles are found marginal sense organs or *lithocysts* (one per tentacle) which co-ordinate swimming movements.
9. The plan of nervous system is different from II. A plexus of simple nerve fibres over the subumbrellar surface between the ectoderm and the muscle layer is found which has per-radial and inter-radial thickenings; round the margin a slight ring-like nervous thickening is also found.	9. Besides a nerve-net on both sides of mesogloea, a double nerve-ring is found at the margin.
10. The **neuromuscular system is better developed** than in II. The muscle fibres are arranged as circular musculature extending over the peripheral part of the subumbrella. The contractile protoplasm of the ectodermal muscle cell is cross striated.	10. The velum and subumbrella possess abundant muscle fibres having a transverse striation.
Points of similarity	*Points of similarity*
11. Free-swimming bell like gelatinous, concavoconvex and marine.	11. Free-swimming, bell-like or saucers shaped, concavoconvex and marine.
12. Bears four **horse-shoe shaped inter-radial gonads ;** the animal is unisexual.	12. Bears four ovoid *per-radial gonads* ; it is unisexual.
13. From the centre of the subumbrella proceeds the manubrium which is short and inconspicuous and bears a four-sided mouth at its free end.	13. From the centre of the subumbrella arises the manubrium. The manubrium is better developed and bears a four sided mouth.
14. The general arrangement of cell layers: *ectoderm* and *endoderm* as well as that of *mesogloea* is like that of II.	14. Same.

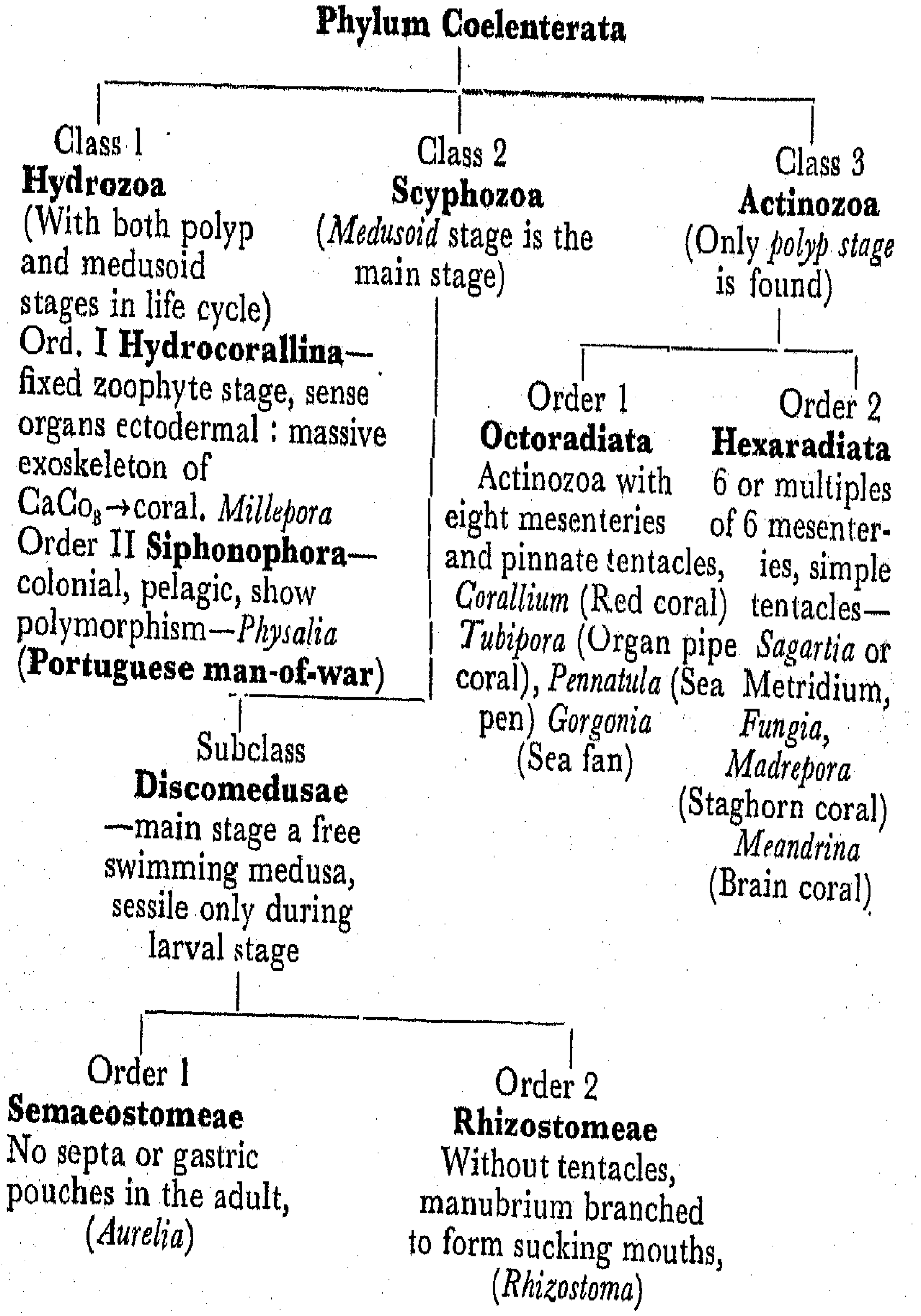
Comparison between the Life-history of Aurelia and Obelia

Life-history of *Aurelia*	Life-history of *Obelia*
1. Zygote →morula →blastula, invagination→two layered planula with open blastopore; **planula** with outer ciliated ectoderm and inner endoderm.	1. Zygote→hollow blastula→immigration of cells at one end→elongated *planula* with an outer layer of ectoderm and a solid core of endoderm. The ciliated *planula* swims freely; the enteron develops in it by delamination of endoderm.
2. The **planula** becomes fixed forming a **hydratuba.**	2. The planula becomes fixed forming a **hydrula.**
3. At the base of hydra-tuba, a horizontal stolon develops and from this fresh hydra-tubae may be budded.	3. The hydrula develops manubrium, tentacles and sends out lateral buds repeatedly and gives rise to asexual *Obelia* colony.
4. The hydra-tuba develops tentacles, gastric ridges and septal funnels and then undergoes **strobilation,** an *asexual multiplicative process* producing a number of ephyrula larvae which are star shaped.	4. No gastric ridges and no septal funnels are found. It does not strobilate. No ephyrula or any stage corresponding to that is found.
5. The *hydra-tuba* is capable of reproducing by budding; it is itself asexual; it can be compared to the asexual *Obelia* colony which also reproduces by budding.	5. The *Obelia* colony represents the asexual stage and is capable of reproduction by budding. By these considerations it is comparable to the **hydra-tuba** of *Aurelia.*
6. The hydra-tuba strobilates and the segmented body comes to be known as scyphistoma.	6. No strobilation occurs.
7. **Scyphistoma** reproduces asexually by segmentation by horizontal furrows and gives rise to *ephyrula* larvae which are saucer shaped and which represent an intermediate stage between the polyp and medusa. The *ephyrula* is also a free-swimming larval stage.	7. Neither *scyphistoma,* nor *ephyrula* is found. In *obelia,* medusa is produced directly from the *Obelia colony,* by a process of asexual budding from the blastostyle. No intermediate stage between *polyp* and *medusa,* corresponding to *ephyra* is found.
8. The *ephyra* undergoes a metamorphosis and becomes the medusoid adult.	8. Metamorphosis does not occur. The medusae are formed from *Obelia* colony directly as buds from the blastostyle.
9. The medusoid form or the sexual generation is the adult *Aurelia.*	9. The medusa is not the adult of *Obelia*; the medusa is only a zooid of the *Obelia.*
10. The polypoid stage represented by the hydra tuba is only a larval stage.	10. The polyp is the adult stage in Obelia.
11. No true alternation of generations is found. The life-cycle is really a metamorphosis complicated by multiplication in the larval stage.	11. True alternation of generations is found, the sexual medusoid one alternating with the asexual polypoid obelia colony.

Aurelia compared with obelia polyp: *Aurelia is medusoid, sexual generation* bearing gonads, elaborate gastrovascular system, an advanced neuromuscular system and sense organs; it is free-swimming. *Obelia* polyp on the other hand is sedentary, hydra-like in structure, without gonads (representing the asexual generation; reproduces by budding (*Aurelia* does not reproduce by budding); the gastric cavity in polyp is simple and no radial canals are found; neuromuscular system is simple; sense organs are completely absent. Thus the adult *Aurelia* presents marked structural and physiological differences from the *Obelia* polyp. The mission of life of adult *Aurelia* is sexual reproduction; it represents an adult with advanced physiology and elaborate structure; the *polyp of Obelia* is mainly a nutritive zooid and does not indulge in sexual affairs, its structure and physiology are therefore relatively simple.

29

Classification of the Phylum Coelenterata



Phylum Coelenterata

- Class 1 **Hydrozoa** (With both polyp and medusoid stages in life cycle)
  - Ord. I **Hydrocorallina**—fixed zoophyte stage, sense organs ectodermal : massive exoskeleton of $CaCo_3 \rightarrow$ coral. *Millepora*
  - Order II **Siphonophora**—colonial, pelagic, show polymorphism—*Physalia* **(Portuguese man-of-war)**
- Class 2 **Scyphozoa** (*Medusoid* stage is the main stage)
  - Subclass **Discomedusae** —main stage a free swimming medusa, sessile only during larval stage
    - Order 1 **Semaeostomeae** No septa or gastric pouches in the adult, (*Aurelia*)
    - Order 2 **Rhizostomeae** Without tentacles, manubrium branched to form sucking mouths, (*Rhizostoma*)
- Class 3 **Actinozoa** (Only *polyp stage* is found)
  - Order 1 **Octoradiata** Actinozoa with eight mesenteries and pinnate tentacles, *Corallium* (Red coral) *Tubipora* (Organ pipe coral), *Pennatula* (Sea pen) *Gorgonia* (Sea fan)
  - Order 2 **Hexaradiata** 6 or multiples of 6 mesenteries, simple tentacles—*Sagartia* or Metridium, *Fungia*, *Madrepora* (Staghorn coral) *Meandrina* (Brain coral)

Class **Hydrozoa**, order **Hydrocorallina** :

Millepora : surface bears minute pores of which the larger *gastropores* (through which gastrozooids protrude out) are surrounded by the smaller *dactylopores* (through which the dactylozooids protrude out). When dried, the colony leaves an irregularly branched and lobed mass of corallum ($CaCO_3$). The whole flattened calcareous mass of coral is called **coenosteum.** *Gastrozooids* : thick, broad and short with 4 to 6 knobbed tentacles. *Dactylozooids* : long filamentous and mouthless with irregularly disposed hollow capitate tentacles. Reproductive bodies **'gonophores'** lodged in special rounded chambers called *ampullae* ; gonophores produce small free swimming medusae.

Hydrozoa—Siphonophora

Physalia (**Portuguese man-of-war**) : reduced coenosarc : has a large cup-shaped brilliant peacock blue or orange, bladder-like **float** or **pneumatophore** which remains above the water-surface. No nectocalyces or swimming bells. Three kinds of zooids hang from the underside of the float : (i) **gastrozooids,** feeding individuals, are ordinary polyp-like, (ii) **dactylozooids** form a driftnet, bear (several feet) long and retractile tentacles beset with batteries of nematocysts ; the tentacles contract and carry the prey towards the mouth of the gastrozooid. By means of its driftnet *Physalia* can prey upon and devour an adult mackerel (a food fish) ; its nematocysts are highly poisonous and may even imperil a human being : this is known by the experience of divers, (iii) the **gonozooids** look like bunches of grapes and they are reproductive zooids. Each gonozooid consists of a stalk, the gonodendra, gonophores and the gonopalpons ; the gonopalpons are tentacle-like dactylozooids associated with gonozooids.

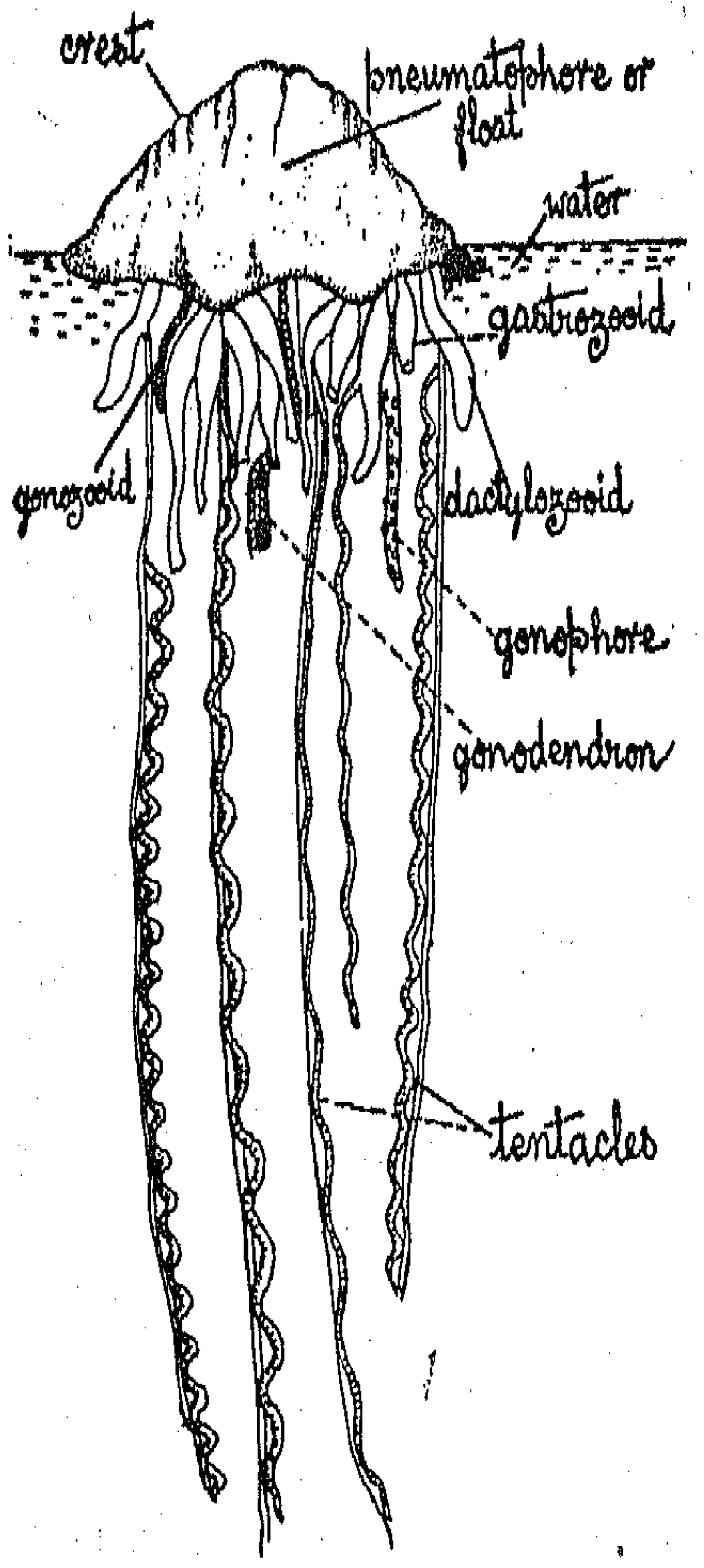


Fig. 127. Physalia (Portuguese man of war).

Class **Scyphozoa**, order Rhizostomeae

Rhizostoma is a medusa of very large size : a hat-shaped umbrella : *eight* long and lobed *oral arms* which bear thousands of small funnel shaped *suctorial mouths* with frilled edges : thus, a *polystomatous condition* (many mouthed) prevails, a unique feature bec[illegible] animal kingdom. Each of the suctorial mouths lead into a

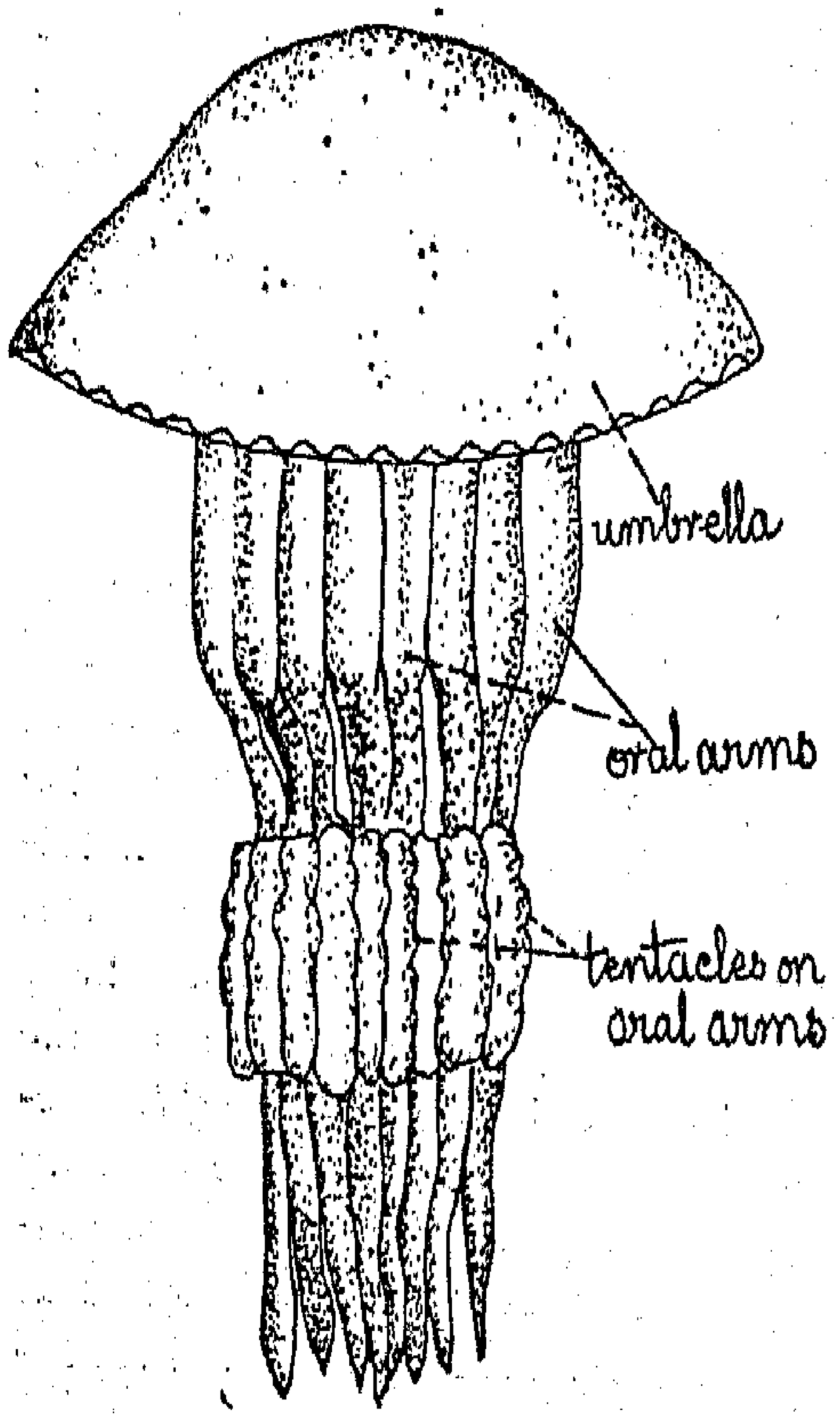


Fig. 128. Rkizostoma.

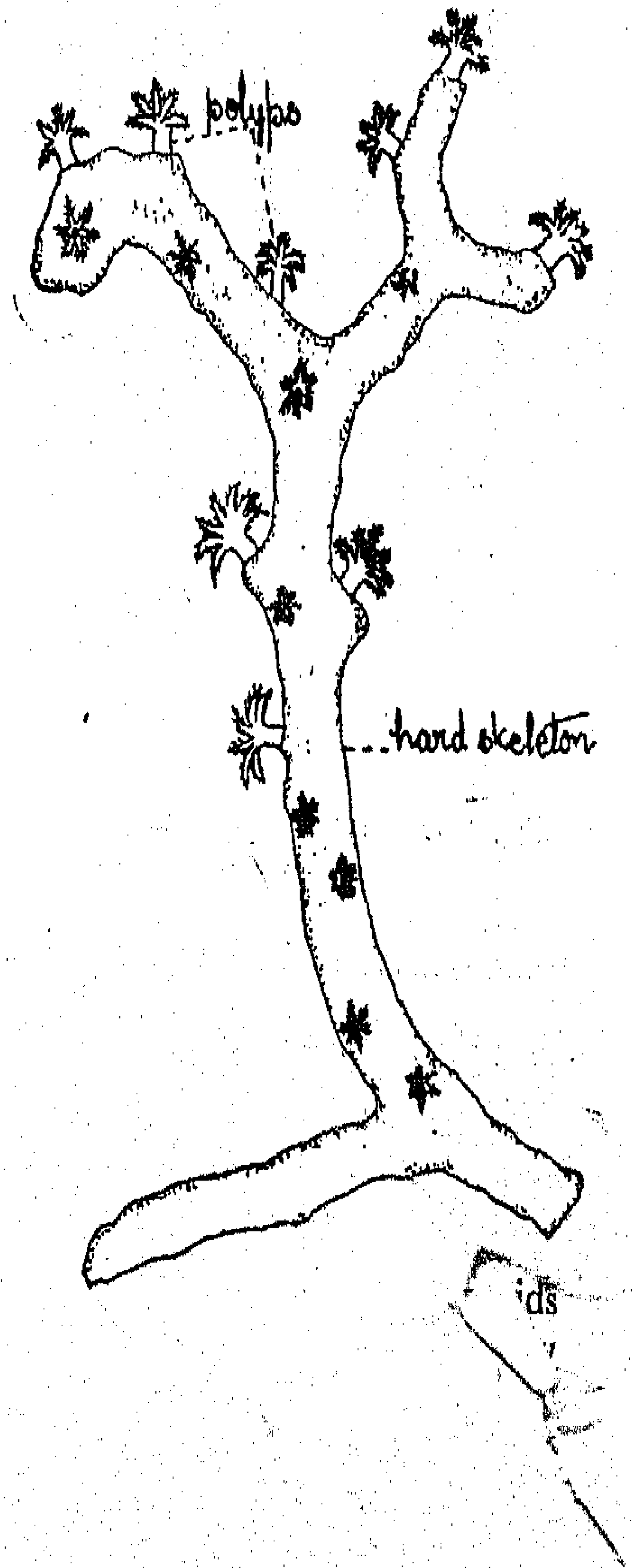


Fig. 129. Corallium rubrum.

canal inside the arm, so that many canals are found traversing the thickness of the arm; these canals open into larger canals; ultimately the system leads into the stomach. Fishes and other preys, often of a large size are caught by the oral arms; the prey is drawn partly into 'sucking mouths' through which the digested food in the form of a fluid is absorbed. *External digestion* occurs when the prey is in contact with the folded 'lips' which act as organs of external digestion.

Class **Actinozoa—Octoradiata : coral**

Corallium (Red coral of commerce) : upright branched dimorphic colony with two kinds of zooids (i) *autozooids* which feed and nourish the colony and (ii) *siphonozooids* (with reduced mesenteries and enlarged siphonoglyph) which maintain a circulation of water in the canals of the colony and which bear gonads; planula develops inside the zooid (viviparity). The red hard coral substance forming the core of the colony is used for making ornaments and is precious. The crust is dark red due to presence of red calcareous spicules.

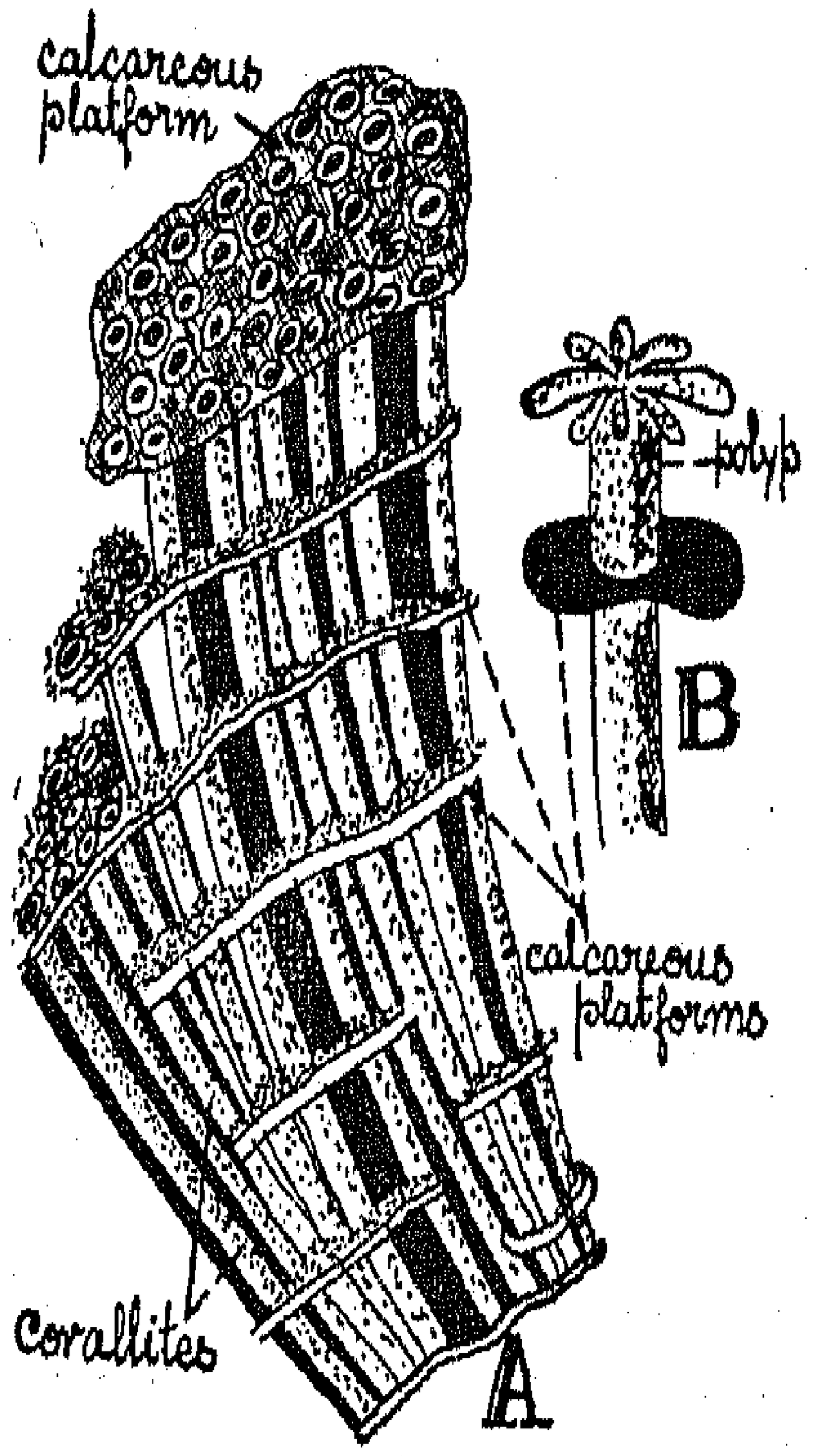


Fig. 130. Tubipora, A, skeleton of colony B, a single polyp.

Tubipora : The skeleton (calcareous) consists of many parallel tubes of corallites which are not in touch with each other but which are held together by horizontal calcareous plates. The walls of the corallites are composed of firmly fitting calcareous spicules. At the apex of each corallite is found a single polyp. The living Tubipora looks green but when the polyps are withdrawn it becomes brick red. The polyps are all of one type.

Pennatula (Sea-pen) : elongated apparently bilaterally symmetrical dimorphic colony, the basal end of its stem remains burrowed in the mud while the distal end of the rachis (or stalk) has paired lateral branches bearing two kinds of zooids : (i) feeding *autozooids* and (ii) *siphonozooids* which have reduced mesenteries and a prominent siphonoglyphe and which draw a current of water inside the canals of the colony. The autozooids are arranged side by side in rows forming uniform lateral branches on each side while the siphonozooids are found at the back of the stem ; the colony appears feather-like, it is capable of movement.

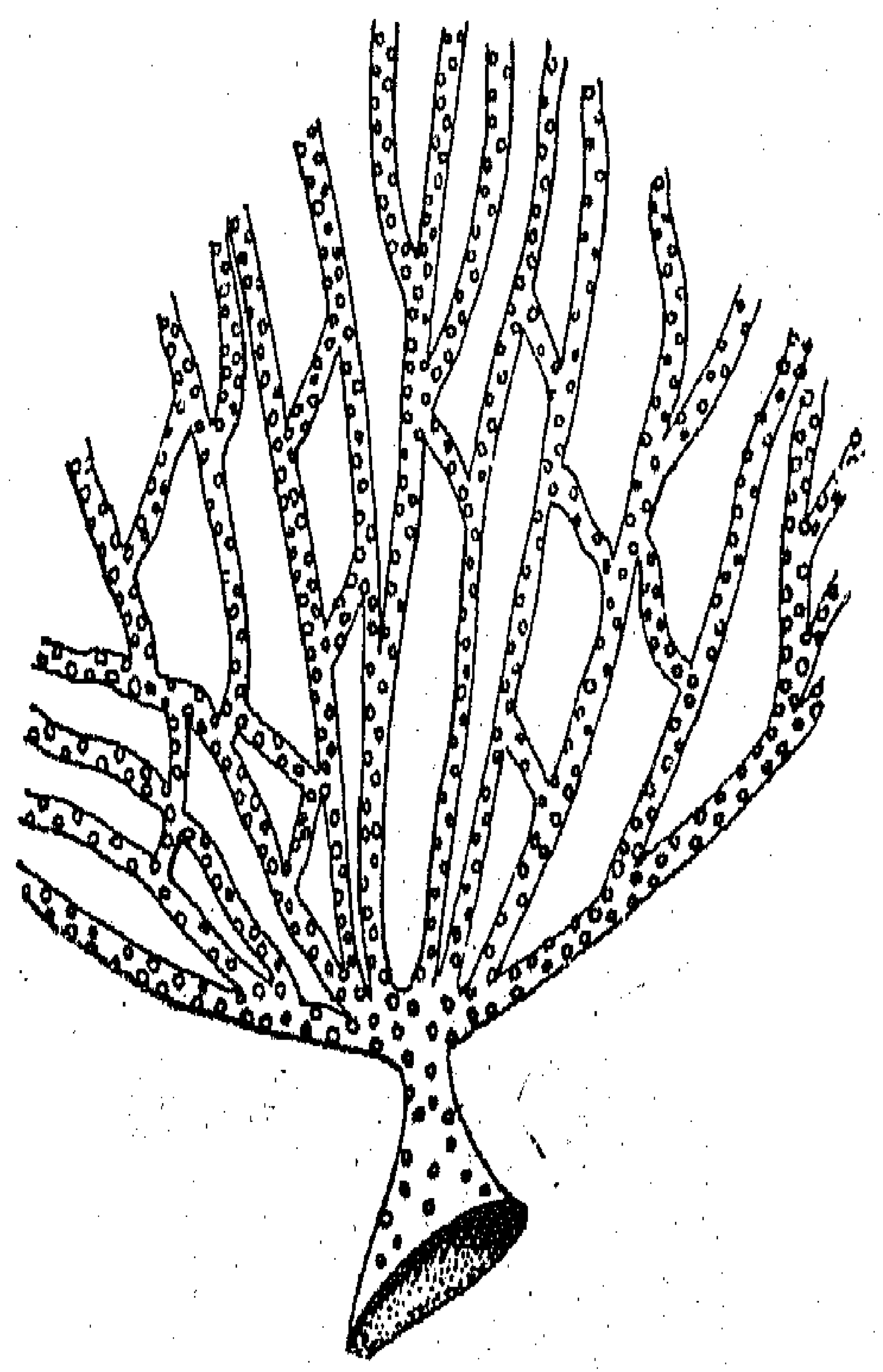


Fig. 131. Gorgonia skeleton of the colony.

Gorgonia (Sea-fan) forms grooves and thickets in tropical seas. Tree-like, upright, branching colony consisting of a horny and flexible axial rod secreted by ectoderm. The skeleton is *not calcareous* but horny. Spicules are present in mesogloea. No siphonoglyphe. The axial skeleton is formed of **grogonin**, a horny substance. The red, yellow or white colony looks like a fan at the top.

Class Actinozoa—order **Hexaradiata**

Sagartia or *Metridium* (Sea anemone) exclusively marine, single, without skeleton, found on shores. Capable of locomotion by slow creeping movements at its base. Flower like, brilliantly coloured polyps with three parts : *oral disc, pedal disc* and *cylindrical column* in their body. Oral-cone lacking. *Tentacles*, very numerous, arranged in several circlets. A highly developed muscular system. A *stomodaeum* or gullet lined with ectoderm+; *coelenterom* divided up into chambers by *mesenteries*, vertical radiating partitions which, in upper part of the polyp connect the body wall with the stomodaeum. Reproductive elements are developed in the endoderm of mesenteries and not on a medusa. The flattened cylindrical gullet bears on its inner surface (one at each end) two longitudinal grooves called siphonoglyphes. The body wall contains ectoderm, endoderm and mesogloea as usual. In their life history no alternation of generations occurs.

Fungia (Mushroom shaped coral) has a discoid corallite. The septa are connected by special calcareous rods, *synapticula*. A solitary form, a big individual. *Madrepora* (Staghorn coral) has a slender tree like colony. A common calcareous stem, the *coenenchyme* is formed by calcification of coenosarc and gives origin to the individual corallites. Growth is vertical. *Meandrina* (Brain coral) has massive encrusting colonies with confluent zooids with septa arranged in rows. The surface bears ridges and grooves and the coral is known as Brain coral due to resemblance to the ridges and grooves of brain ; the skeleton has a convoluted surface.

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Polymorphism in Coelenterata

When a single organism is represented by more than one kind of individuals which differ in form and which perform different functions, the organism is said to be *polymorphic* and the phenomenon is described as **polymorphism.** Polymorphism enforces division of labour : different individuals or zooids are specialised for different functions.

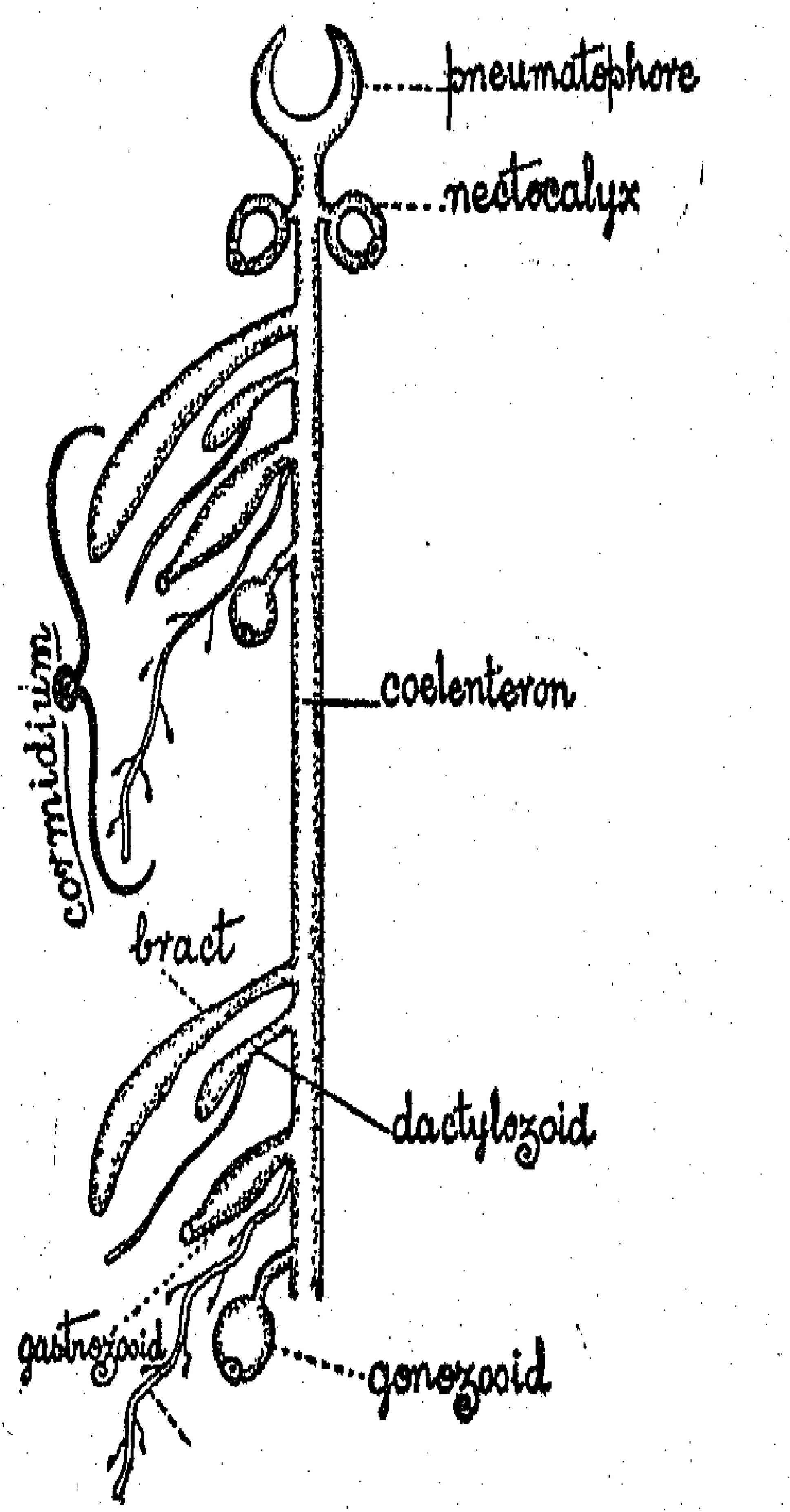

Fig. 132. Structure of a typical siphonophore.

As many as seven different kinds of zooids are met with in the coelenterata : (i) *gastrozooids* concerned with feeding (ii) *dactylozooids* for offence and defence (iii) *blastostyle* for producing medusae by budding ; these three are modified polyps, (iv) *medusae* for producing ova and sperms (v) *hydrophyllium* or *bract*, leaf like

function as *adhesive organs* the scolex remains attached to the mucous membrane of the intestinal wall. The dorsal and the ventral surfaces of the animal have no superficial differentiation ; the surface towards which the female reproductive organs are nearer is the ventral side and this fact can be ascertained in a section of the animal under microscope. A minute *genital papilla* bearing the opening of the *genital atrium*, the small chamber into which both the male and the female reproductive ducts open) is found alternately on the right and left borders of the successive proglottides set in the linear series.

The body is invested by a *thick* **protective cuticle** below which is a layer of *longitudinal muscle.* A layer of *circular muscle* divides the parenchyma into a *medullary* and a *cortical region* ; the former contains the reproductive and excretory organs as well as nerves. Nutrition is secured by absorption of the digested food of the host through cuticle, there being *no trace of digestive system in Taenia* : **mouth and alimentary canal are absent.**

An **osmoregulatory system** consisting of flame cells, collecting canals and certain longitudinal main canals (*paired canals* running behind from scolex which are connected by transverse ducts lying in the posterior margin of the proglottides ; on each side there are two longitudinal canals, one *dorsal* and one *ventral*, in the posterior region of strobila, the dorsal canal is last ; in the last proglottid the longitudinal canals join together into a *caudal vesicle* opening to the exterior by an *excretory pore*). In a mature tape-worm, the last proglottis along with the caudal vesicle is dropped off. Fluid from the body is absorbed into the flame cell wherefrom it is driven into narrow tubule or the fine capillary wherefrom it finds way into the main longitudinal excretory trunks and therefrom to the exterior.

The **nervous system** consists of *two ill-defined ganglia* in the scolex, connected by a *nerve ring* and a transverse band of nervous tissue, the *transverse commissure* (or the *cerebral commissure*). From the ganglia nerves proceed to suckers ; in addition a *longitudinal nerve* arises on either side from the ganglion of its side and runs up to the posterior end of the body lying outer to the longitudinal osmoregulatory canal.

In the strobila, the anterior region is sexually immature, the *middle region is sexually mature* and the posterior region is gravid. Each proglottis of the middle region is hermaphrodite. In the posterior ripe or *gravid region*, and *uterus* is distended with eggs and the other parts are reduced.

The **male** organs are *testes* (numerous rounded follicles imbedded in the medullary parenchyma), *vasa efferentia* which ultimately form a *vas deferens* ; the last part of the vas deferens runs through a protrusible process, the *cirrus* and opens at its tip by the *genital pore* in a small chamber the *genital atrium* into which the *female genital pore* also opens. The cirrus is covered over at its proximal side by a muscular *cirrus sac.* The **female organs** include a bilobed ovary lying in the posterior region of

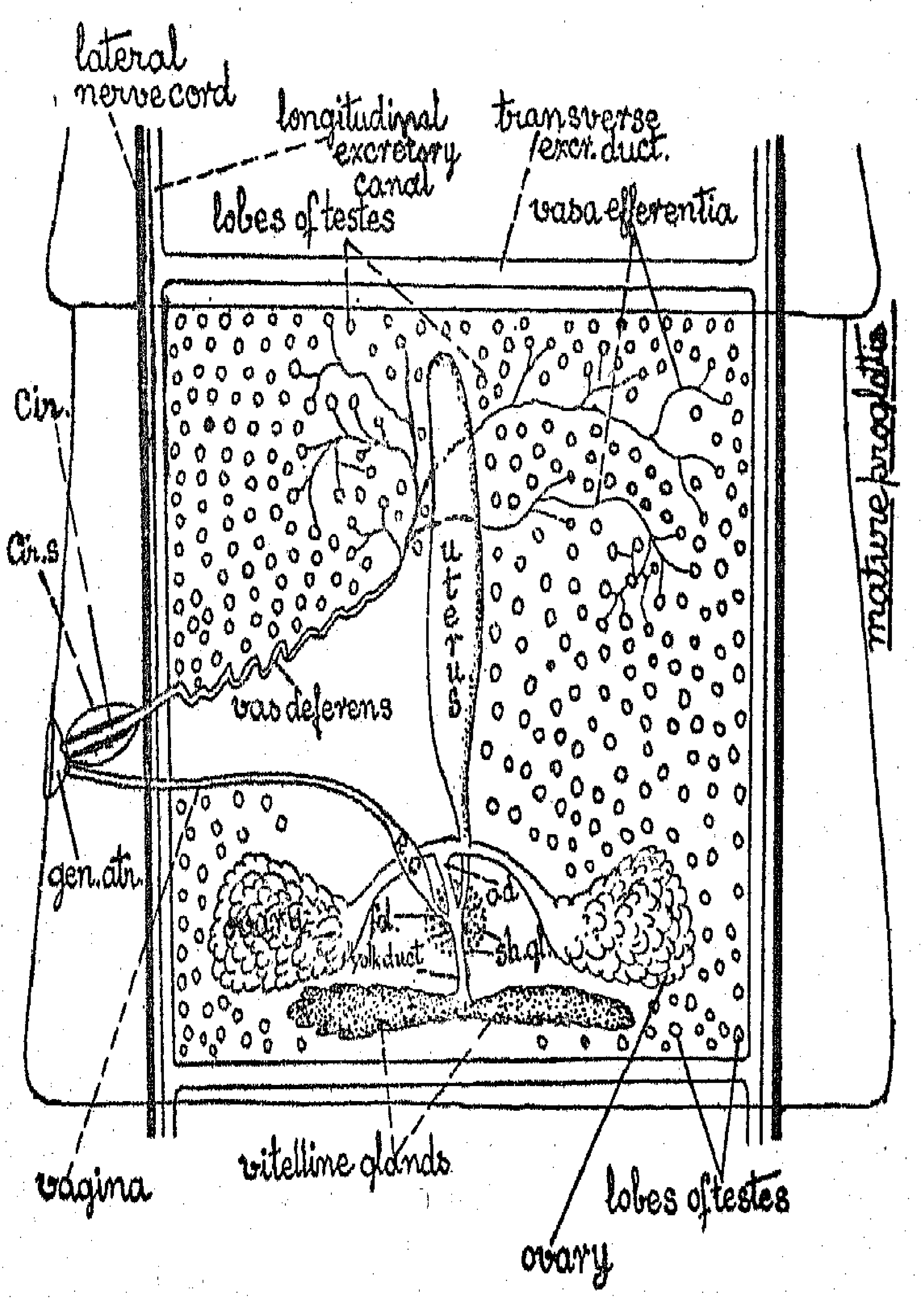

Fig. 149. Reproductive organs of Taenia solium in a mature proglottis of Taenia solium as seen under microscope (semi diagrammatic) cir., cirrus; cir., s, cirrus sac; fp., fertilizing duct; gen. atr., genital atrium; o.d., oviduct; R. C, receptaculum seminis; sh. gl shell glands.

the proglottis, *oviduct*, a yolk or *vitelline gland*, *shell glands*, *ootype* from which a blind sac-like *uterus* arises which does not open to the exterior, the *female genital pore*→the narrow passage *vagina*→*receptaculum seminis* (which has plenty of sperms received as a result of copulation)→*fertilizing duct* opening into the oviduct.

For self-fertilization, the everted *cirrus* enters into the *vagina* of the same proglottis through the female genital pore. When more than one worms are found in intestine, *cross-fertilization* may occur in which the everted *cirrus* of one worm may enter into the *vagina* of the other worm during copulation. In the same worm, the cirrus of one proglottis may enter into the vagina of another proglottis. *Fertilization occurs in the ootype,* the part of

the oviduct where yolk duct and shell glands open and wherefrom the uterus also arises. The fertilized eggs become surrounded by the yolk material in the region of the ootype; the eggs soon become enclosed in a chitinous shell formed by the secretion of the shell glands. The completed eggs are stored in the greatly distended *uterus* which comes to occupy the major portion of the proglottis; all other organs get correspondingly reduced.

Such segments containing distended uterus with shelled eggs are called **gravid** or **ripe proglottides** and are found in the posterior region of the body. These are dropped off one by one and are passed out to the exterior through the man's anus along with his faeces.

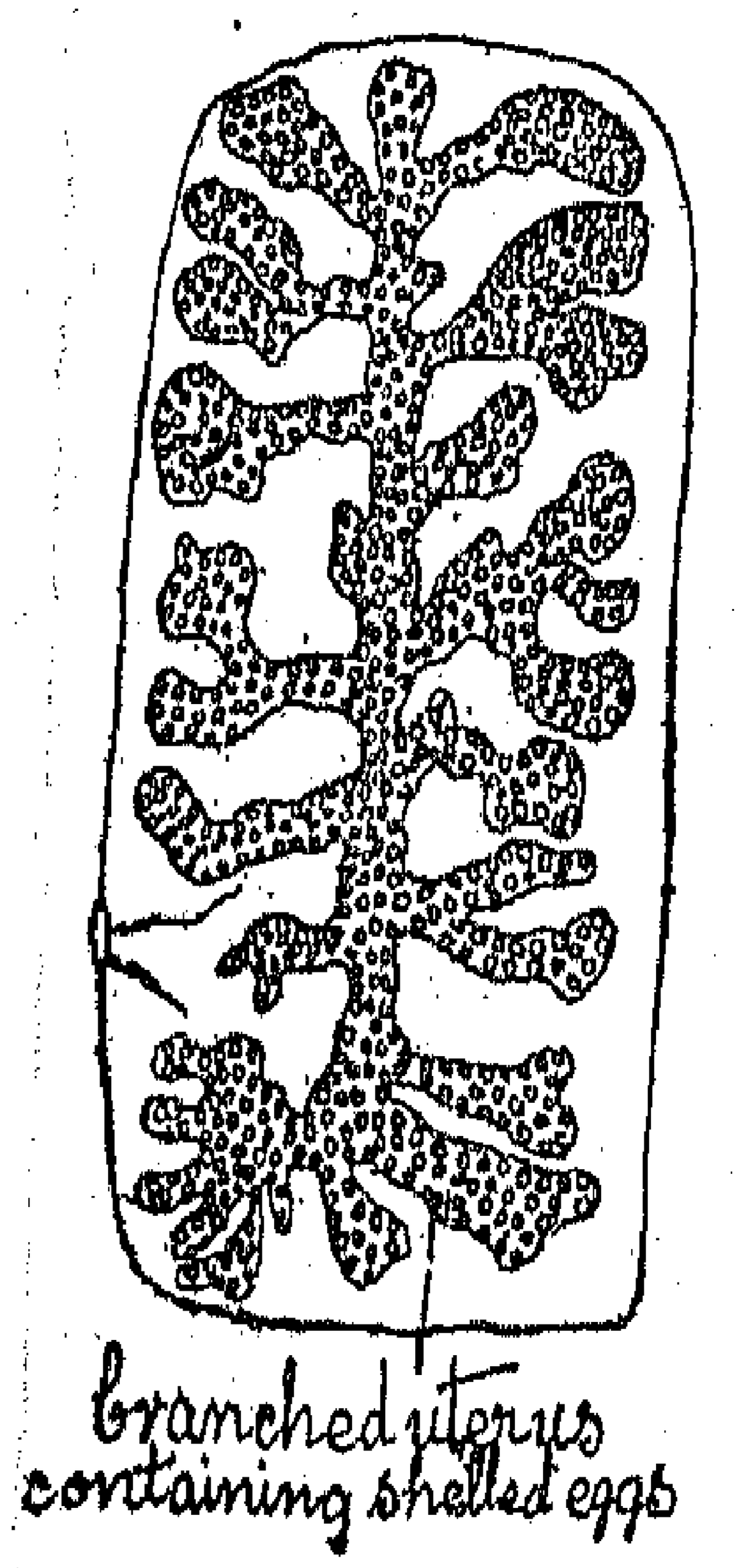

Fig. 150. A gravid proglottis of Taenia solium.

The **pigs** ingest these *gravid proglottides* along with the human faeces upon which they habitually feed. Segmentation starts in

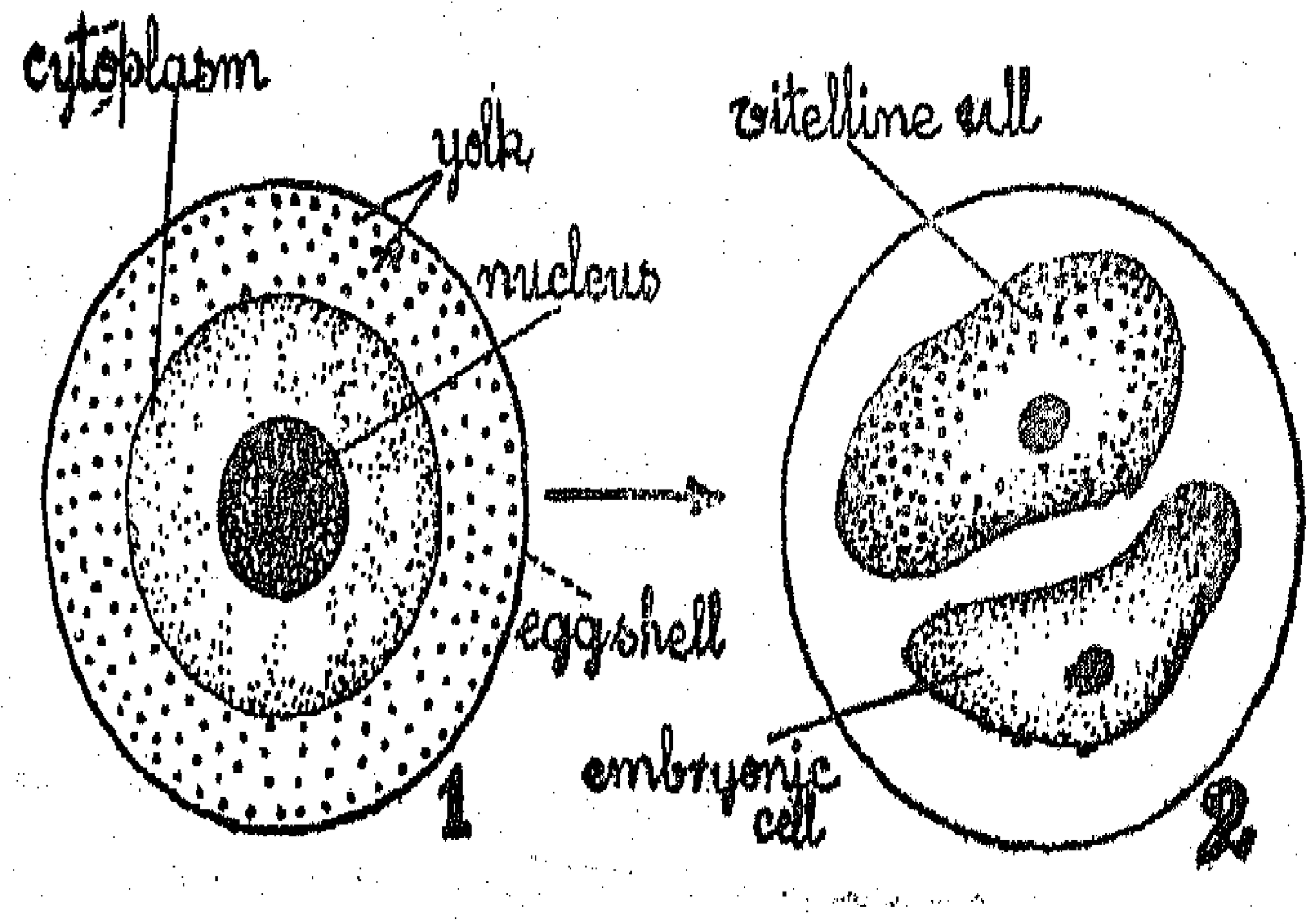

Fig. 151. Diagrams showing (1) fertilized egg and (2) two cell stage.

the fertilized egg even when the gravid proglottis lies inside man's intestine. The egg divides into two cells: the *vitelline cell* and the *embryonic cell*, the latter multiplies forming a **morula.** The morula develops a nutritive outermost embryonic membrane and then a chitinous covering the *embryophore.* The micromeres of the morula soon form a small **hexacanth,** an embryo armed with *six chitinous hooks.* A hexacanth along with its coverings is known as an **onchosphere.** The gravid proglottides passed out with human faeces contain plenty of onchospheres. A single gravid proglottis may contain 30,000 to 40,000 onchospheres.

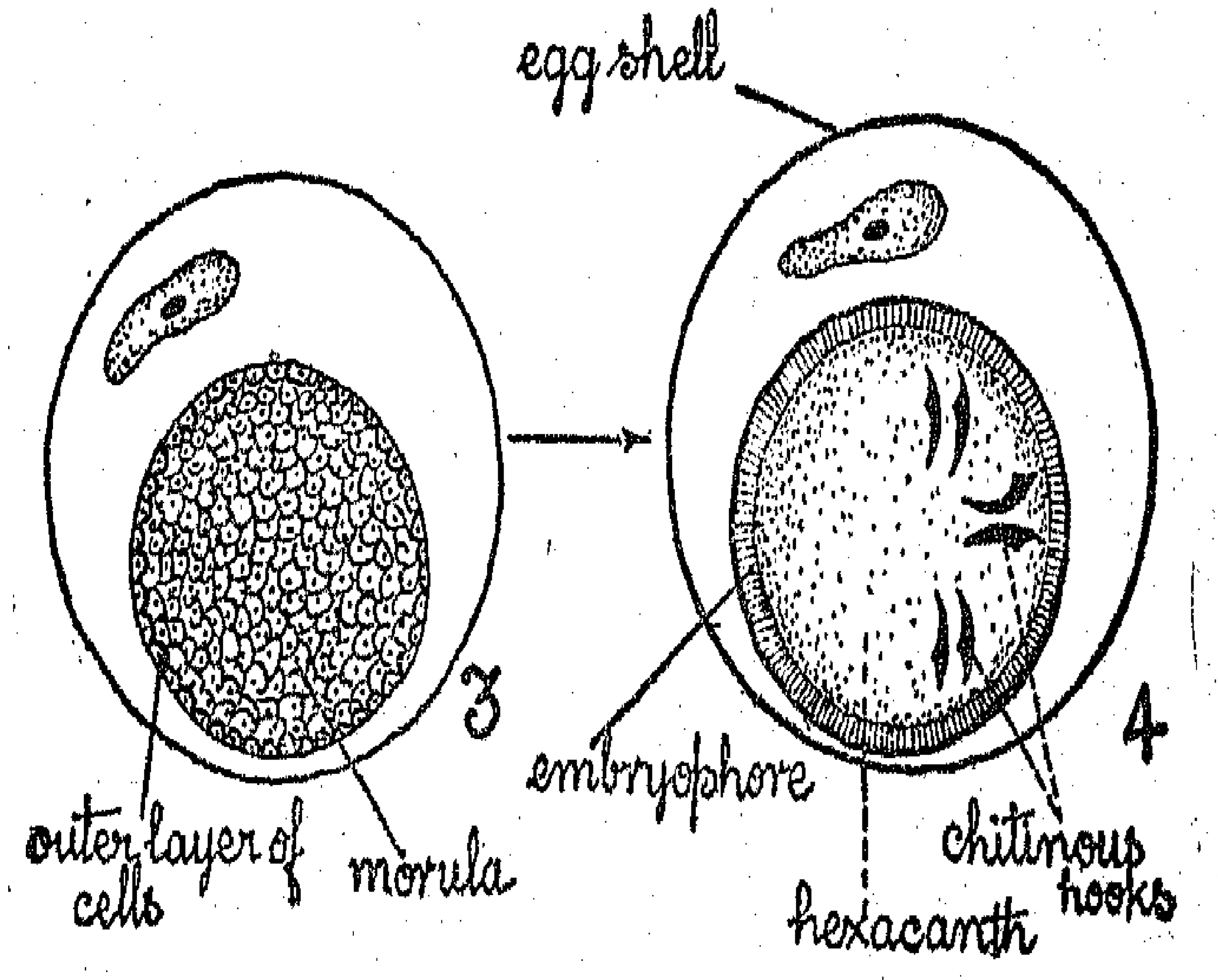

Fig. 152. Formation of hexacanth (Diagrammatic sketches).

Inside the **pig's** intestine, the egg shell and the embryophore of the enchospheres are digested and the hexacanth embryo's are released. The hexacanths penetrate into the intestinal wall of pig, get into the portal circulation and reach the various parts of the pig: muscles etc. During migration, the hooks are all lost and the embryos are lodged in the muscles of the pig's tongue, liver, spleen etc. where they become encysted as small spherical bodies.

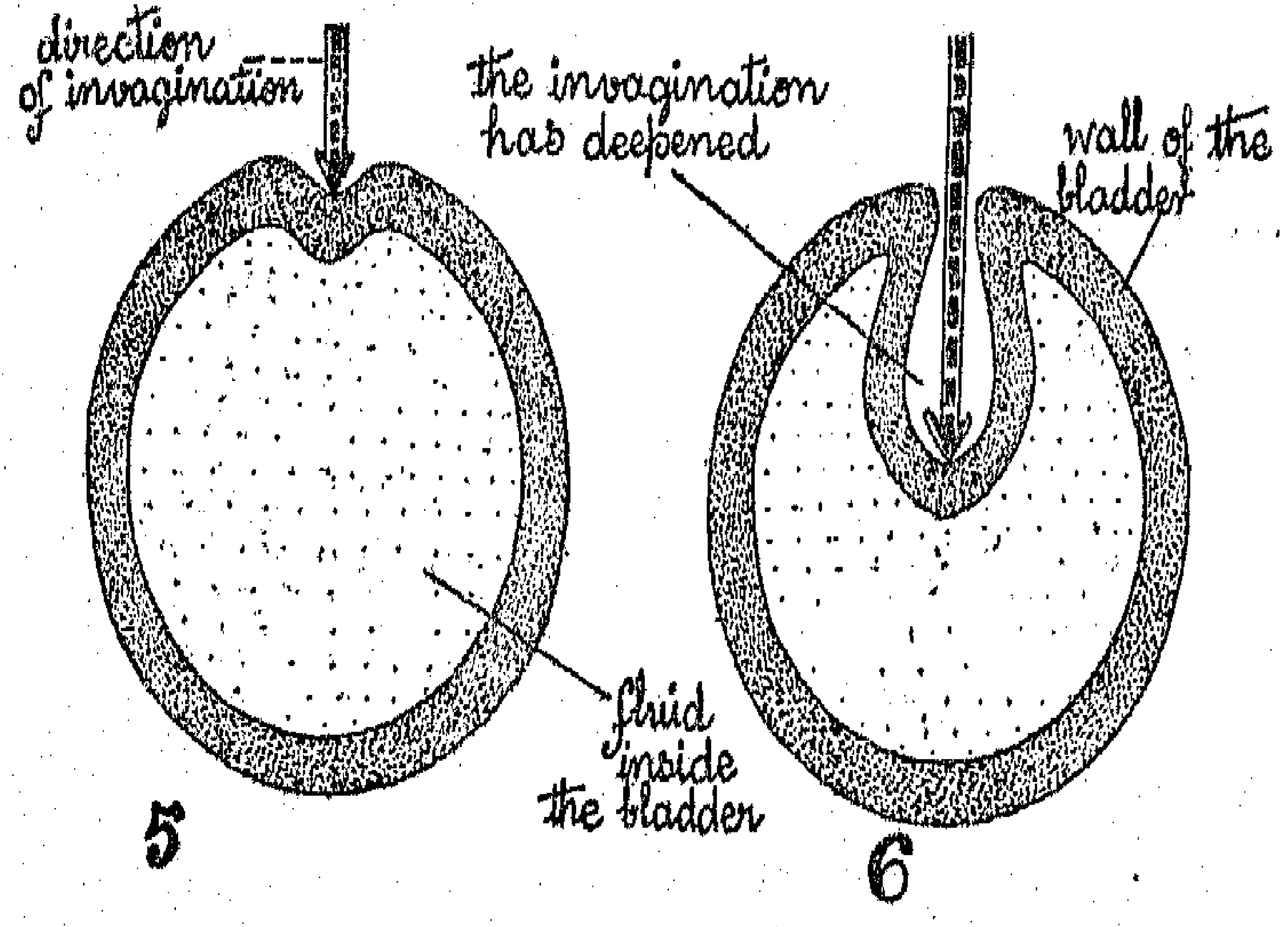

Fig. 153. Diagrams showing invagination in the wall of the bladder.

In each embryo, internal cells dissolve away forming a fluid filled cavity; its wall invaginates, the invagination deepens and develops suckers and hooks facing the cavity of invagination; the embryo is now called a *proscolex.* The invagination evaginates as a result of which the scolex part completely protrudes out and the *hooks* and the *suckers* come to occupy their natural position on the scolex; the embryo is now called a *cysticercus* or *bladder-worm* and remains imbedded in the voluntary muscles of the pig. The infected flesh of pig shows white spots which are due to the bladder worms. Such a flesh is called **measly pork.** A pound of such pork may have as many as 3000 bladder worms.

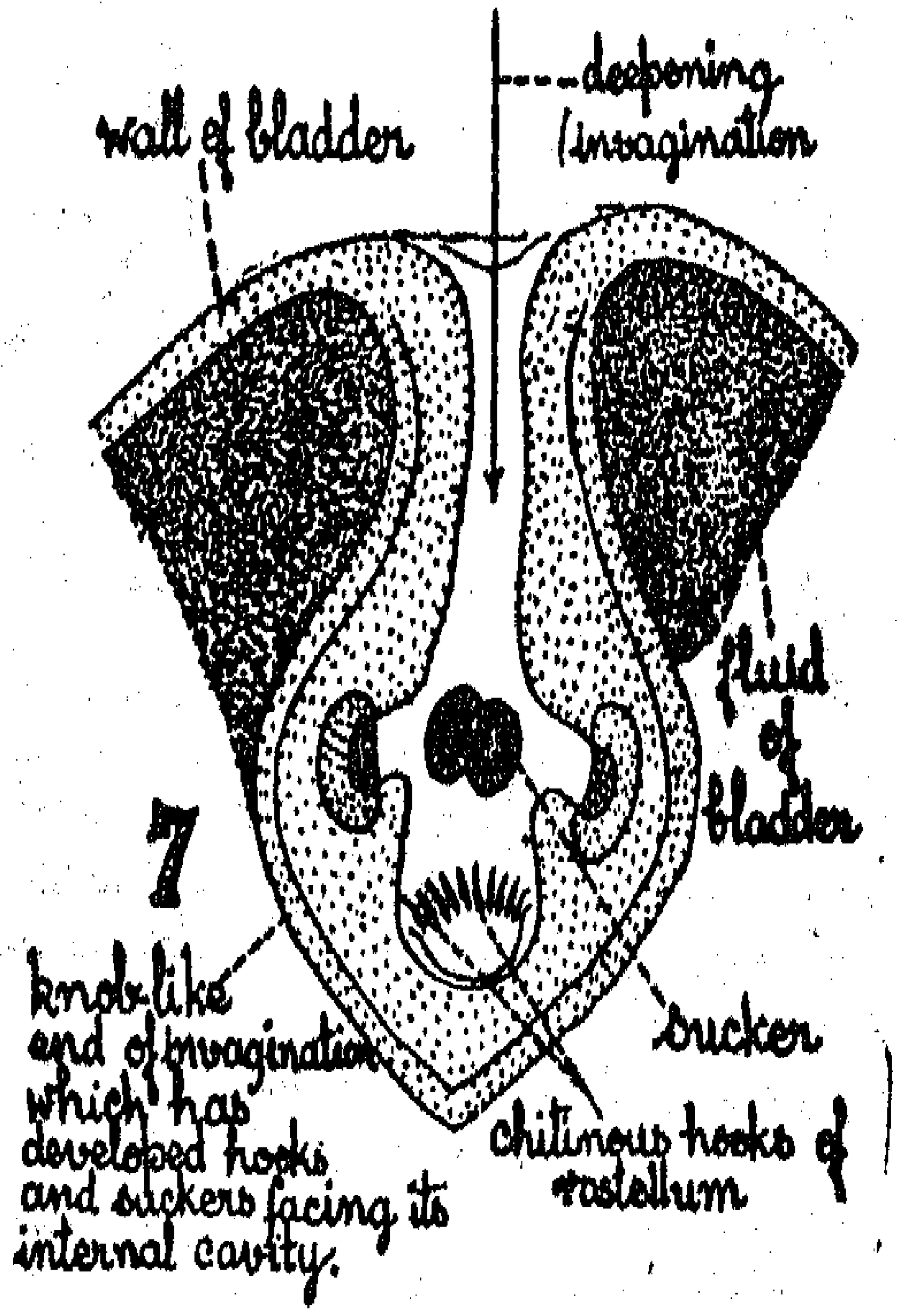
wall of bladder
deepening invagination
fluid of bladder
7
knob-like end of invagination which has developed hooks and suckers facing its internal cavity.
sucker
chitinous hooks of rostellum

Fig. 154. Suckers and hooks develop in the knob-like end of invagination, a proscoiex is formed (After Leuckart).

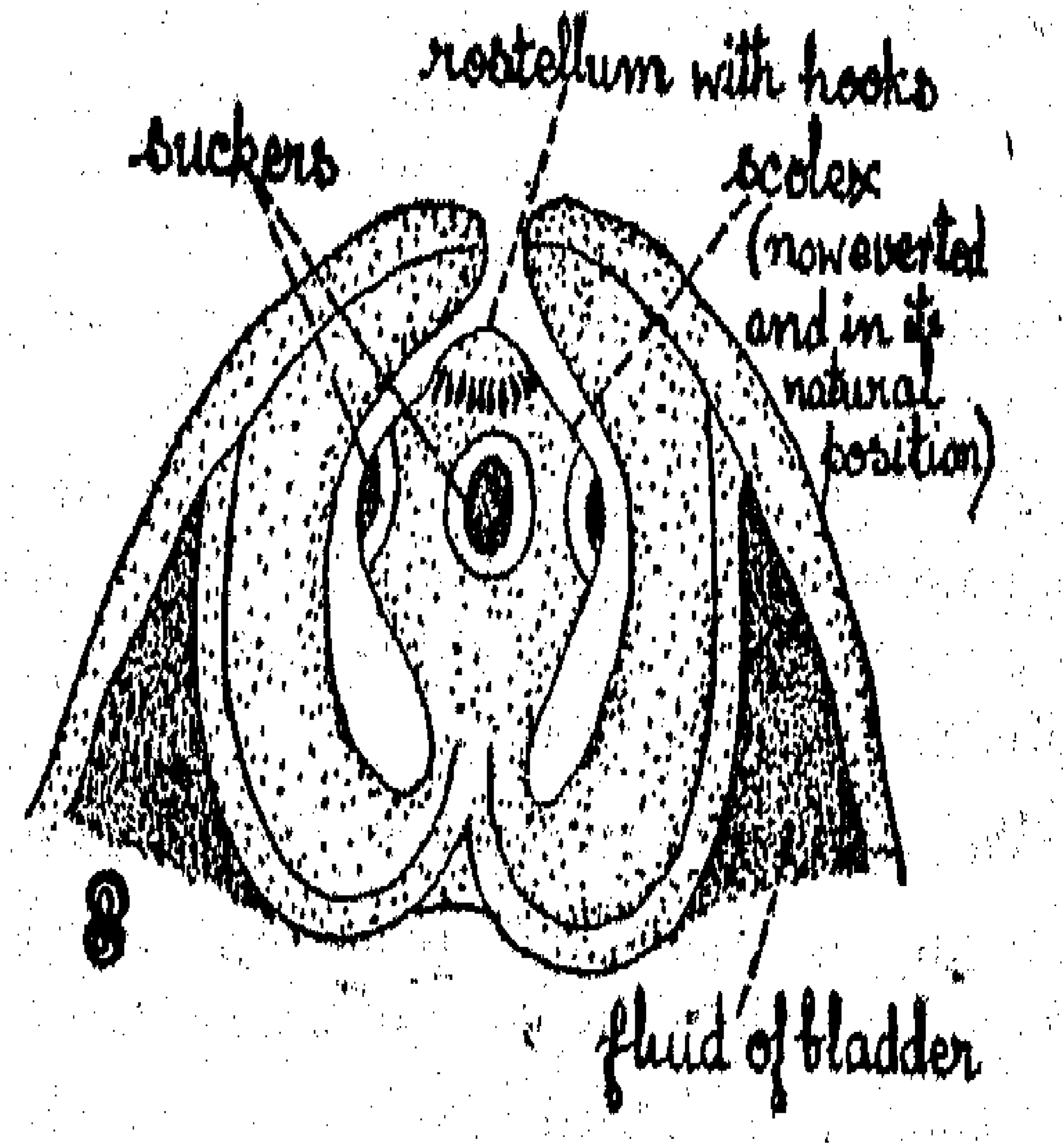

Fig. 155. The proscolex, partly evaginated (After Leuckart).

If **man** eats improperly cooked 'measly pork', the bladder worms reach his stomach; the bladder is thrown off and the scolex gets attached to his intestinal wall. Fresh proglottides are subsequently added on and in course of time, a full tape worm with sexually mature proglottides is formed which drops off *gravid pro-*

glottides containing onchospheres; these are passed out to the exterior with the man's faeces. The pigs which feed upon faeces ingest the onchospheres again and continue the life-cycle. The **man is the primary host** and, the **pig is the secondary host** in the life-cycle.

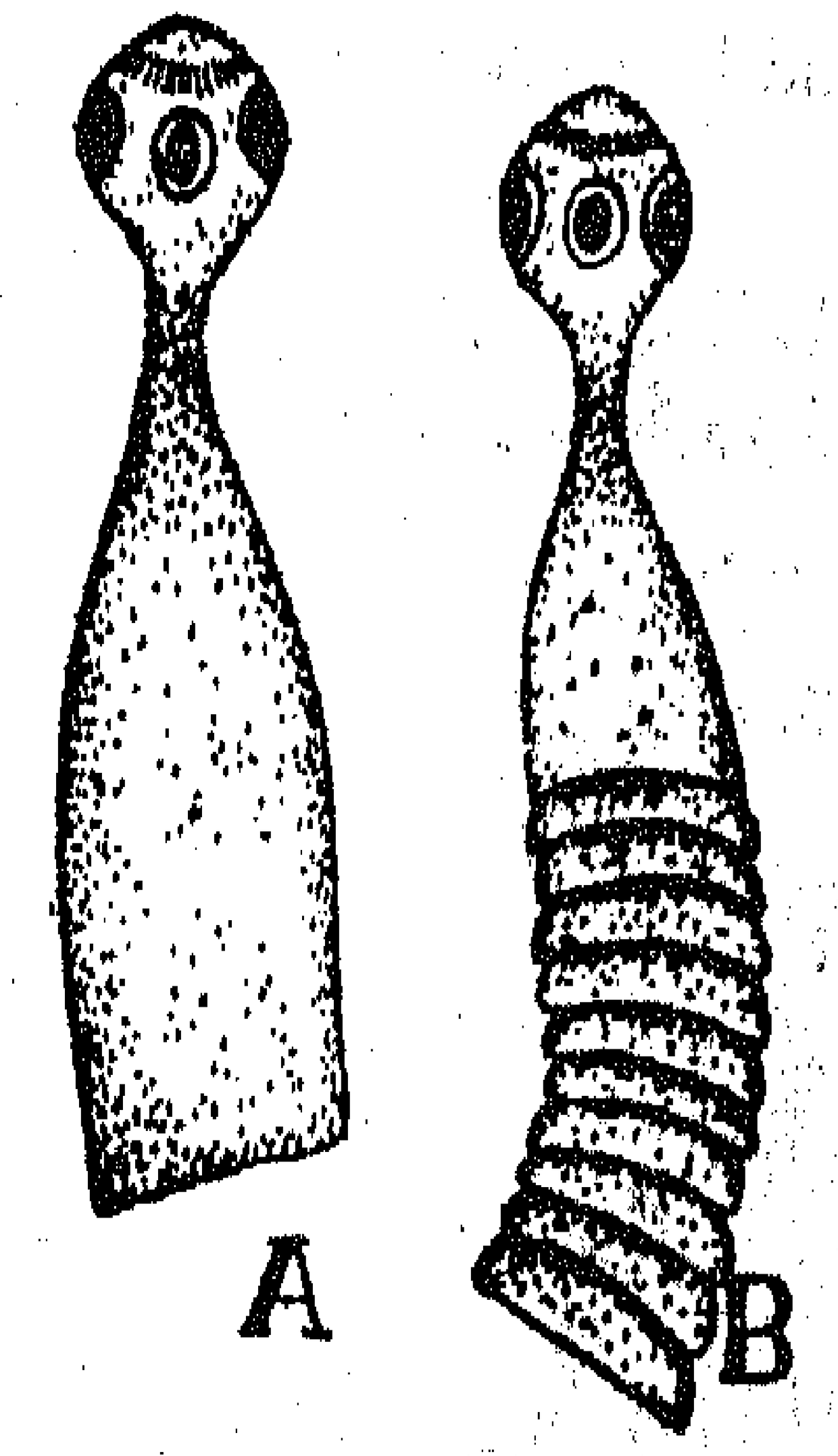

Fig. 156. A, scolex the bladder thrown away, B, scolex with developing neck and strobila.

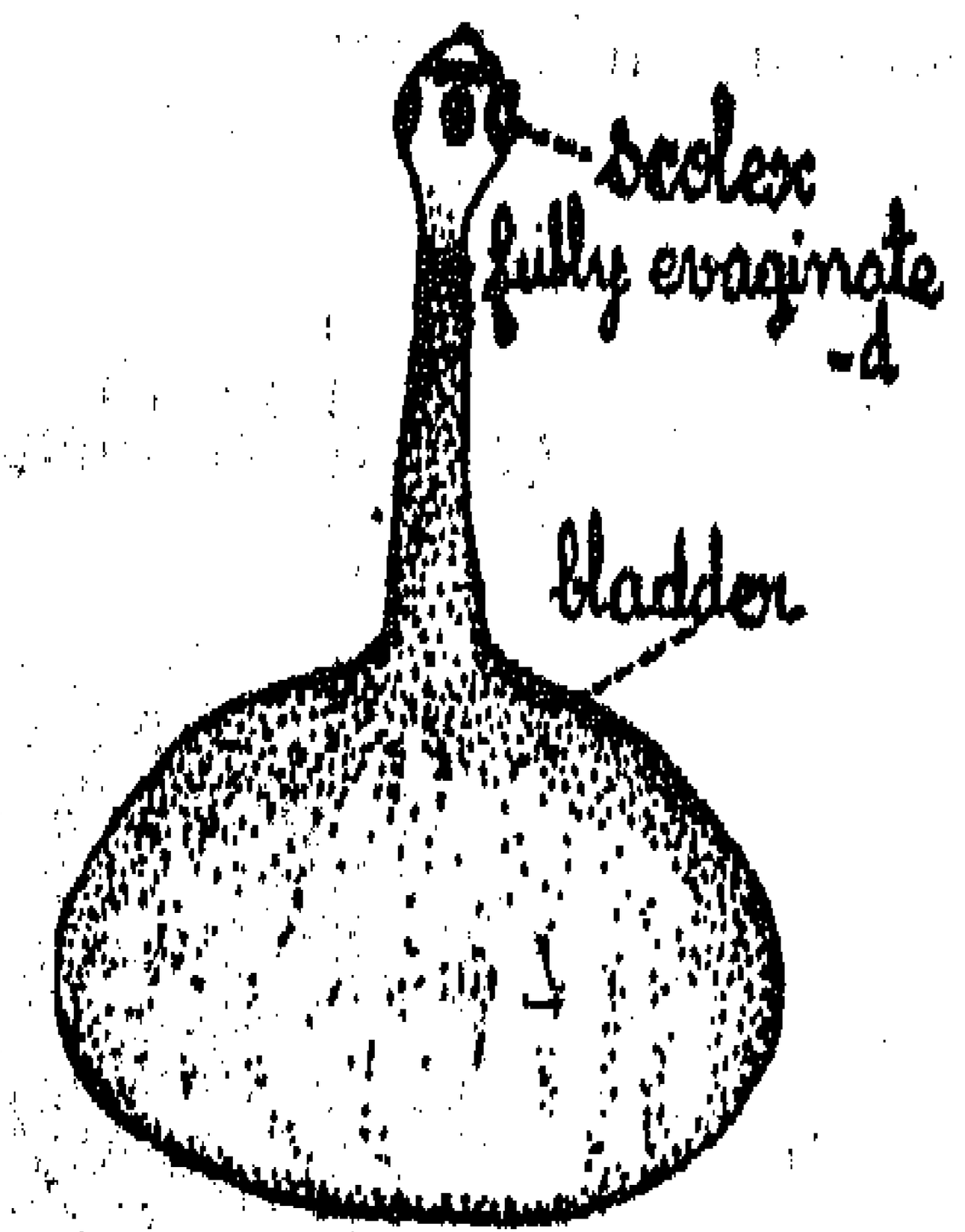

Fig. 157. Cysticercus or bladder worm.

Very rarely onchospheres are swallowed by man in whose muscles *cysticerci* (bladder worms) are formed. No adult tape worm is formed in man in this case. The bladder-worms may establish and encyst in any part of the man's body causing **cysticercosis**, a serious disease. If the cysts settle in eye or brain they cause blindness and serious nervous diseases.

Normally the tape-worms remain attached to the man's intestinal wall by suckers and hooks and cause irritation. It damages the intestinal walls and causes inflammations leading to adverse complications. The tape-worms liberate toxins which may cause *anaemia* and other troubles such as *nausea*, pain in abdomen and nervous disorders. A large number of them naturally deprive the man of his precious food.

Control: Pigs should be prevented to eat any and every thing; adequate sanitary disposal of faeces; the pork should be thoroughly cooked so that the bladder-worms if any, may be killed. These are the preventive measures.

Parasitic Adaptations of Taenia solium

1. A highly *resistant cuticle* (composed of highly insoluble types of protein), envelops the body of the tape worm.
2. Presence of specialised *adhesive organs* : *hooks* and *suckers*.
3. Complete *absence of locomotory organs*: a sequel to the attached endoparasitic life.
4. Sense organs are not developed.
5. Complete loss of alimentary canal.

6. Presence of a highly complicated reproductive system possessing powers of large-scale egg-production. A single animal has many sets of reproductive organs. Enormous production of offsprings is a *natural insurance* for perpetuation of the species.
7. Complex life-cycle.
8. The onchospheres armed with six hooks, the subsequent cysts and the bladder-worms are all very well adapted to their own circumstances of life.

33

Classification of Platyhelminthes

Platyhelminthes are free-living or parasitic, dorsoventrally compressed, bilaterally symmetrical triploblastic metazoa. *Anus*[1], coelom and *haemocoel* are all absent. Nervous system+, flame cells+, complicated reproductive system, *hermaphroditism* common. Eggs yolked. No blood vascular system, no skeletal system and no metameric segmentation. Space between the gut and the body wall packed up with mesenchyme cells which form the parenchyma.

Cl. 1. **Turbellaria** [Freeliving, usually not parasitic, with a gut, ciliated epidermis, no proglottides, suckers rare, epidermis has rhabdites.] Order 1. **Tricladida** gut with an anterior and two posterior diverticulated limbs *Planaria.*

Cl. 2. **Trematoda** [Parasitic, no cilia in adult, thick cuticle+, digestive tract +, anus mostly absent, oral and ventral suckers present.] Order 1. **Monogenea** [Oral suckers feeble or absent, posterior sucker complex and well developed; no alternation of hosts. *Polystomum* and *Diplozoon.* Order 2. **Digenea** [With two or more hosts in life-cycle, suckers simple without hooks or spines, an anterior *oral* and a *posterior* sucker present.] *Fasciola, Schistosoma* and Paramphistomum.

Cl. 3. **Cestoda** [Exclusively endoparasitic, no digestive system, no cilia on ectoderm, thick cuticle, scolex+, adhesive organs+, proglottides formed, hermaphrodite. Subclass 1. **Cestodaria** No proglottides.] [Subclass 2. **Eucestoda** Scolex present, proglottides are formed. Order **Cyclophyllidea** Scolex with 4 suckers, rostellum has hooks; *Taenia*, *Cotugnia* and *Raillietina* (pigeon), *Echinococcus* (dog) *Dipylidium* (cat or dog).

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[1] [An anus may be rarely present.]

Trematoda—*Monogenea.*

Polystomun lives as a parasite in the urinay bladder of frogs and toads and in the nasal cavity of turtle; the opisthaptor bears **six suckers** and many chitinous hooks. Mouth+—pharynx+—oesophagus —intestine with two main diverticulated branches which unite in the posterior body-region; two lateral excretory canals+. Eyes absent. A *vagina* or *copulation canal*[1]+ on each side, it receives the *penis* in copulation. Eggs laid in urinary bladder of frog—exterior in water— a *free swimming ciliated larva*, becomes attached to internal gills of frog's tadpole, loses its cilia, eyes, from the branchial cavity of frog—digestive tract—urinary bladder.

By now the tadpole has become a frog and *Polystomum* finds itself in the frog's bladders. *It* takes 3 yrs. to attain sexual maturity and then lays eggs which pass out to the exterior through the

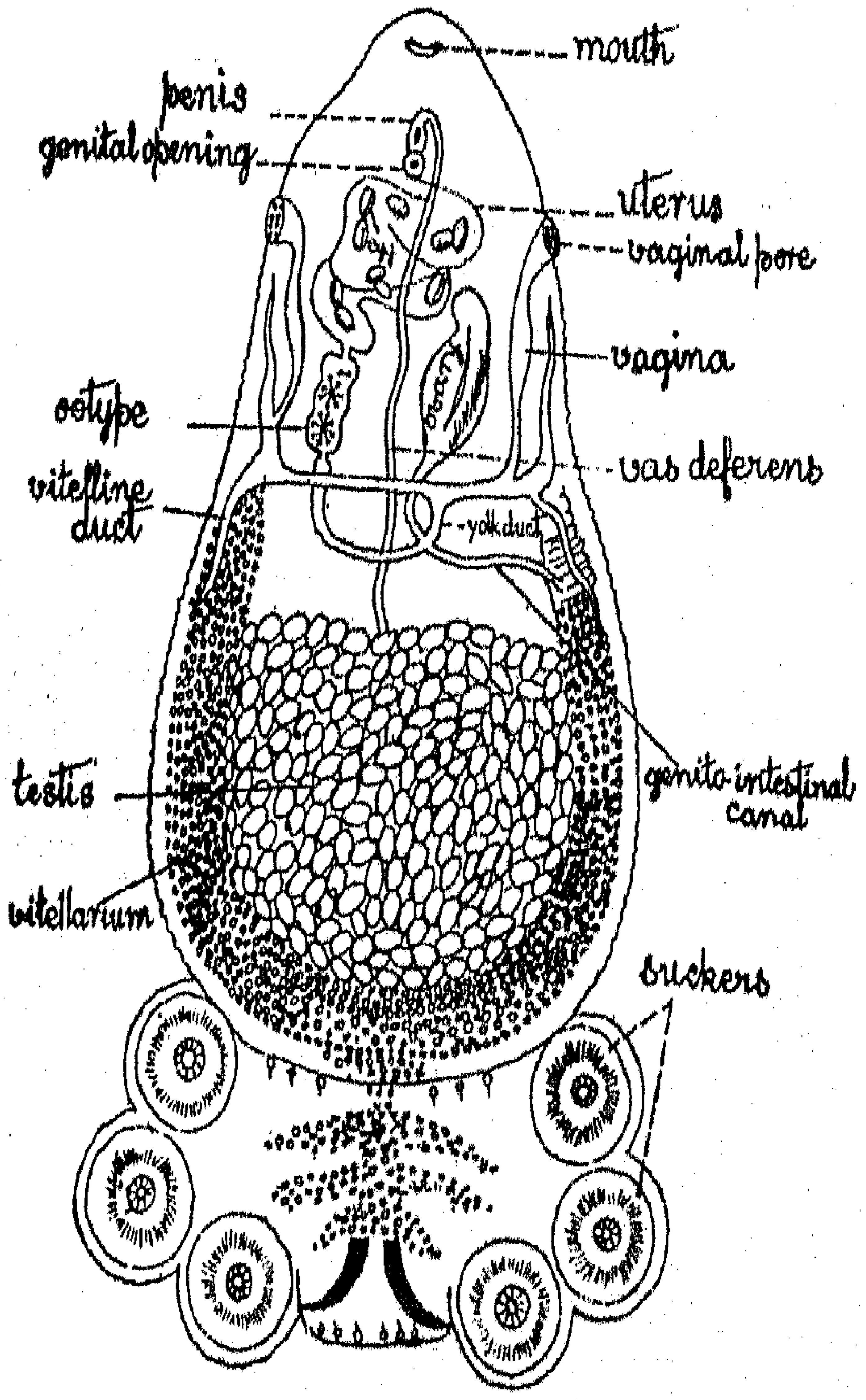

Fig. 154. Polystomum integerrimum, Ventral view showing the reproductive system (After Zeller).

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[1] [The sign of+means that the structure is present.]

cloacal opening and again develop into larvae. The larva is *ectoparasitic* on gills of tadpole while the adult is *endoparasitic* in the bladder of adult frog.

Diplozoon lives attached to the gills of a small fresh water fish, the minnow. It is an ectoparasitic monogenetic trematode. The two adults remain attached throughout life in a pose of permanent copulation. The larvae attach themselves to the gills of the host but they do not develop reproductive organs until they meet another larva. When two larvae meet; they fuse in their middle region; after fusion, the generative organs develop and growth occurs in such a manner that the vas deferens of one from becomes permanently connected to the genital atrium of the other. Thus they remain in permanent copulation throughout their lives. Each individual has both male and female reproductive systems; the two attached individuals cannot be separated. Each individual has a *disc* in the posterior region with eight suckers. The *disc* also bears suckers and hooks. Sperms are easily transferred into the other individual's oviduct during fertilization. The egg capsule has a very long filament by which it attaches to the gills of fishes. The ciliated larva is known as the **Diporpa larva.**

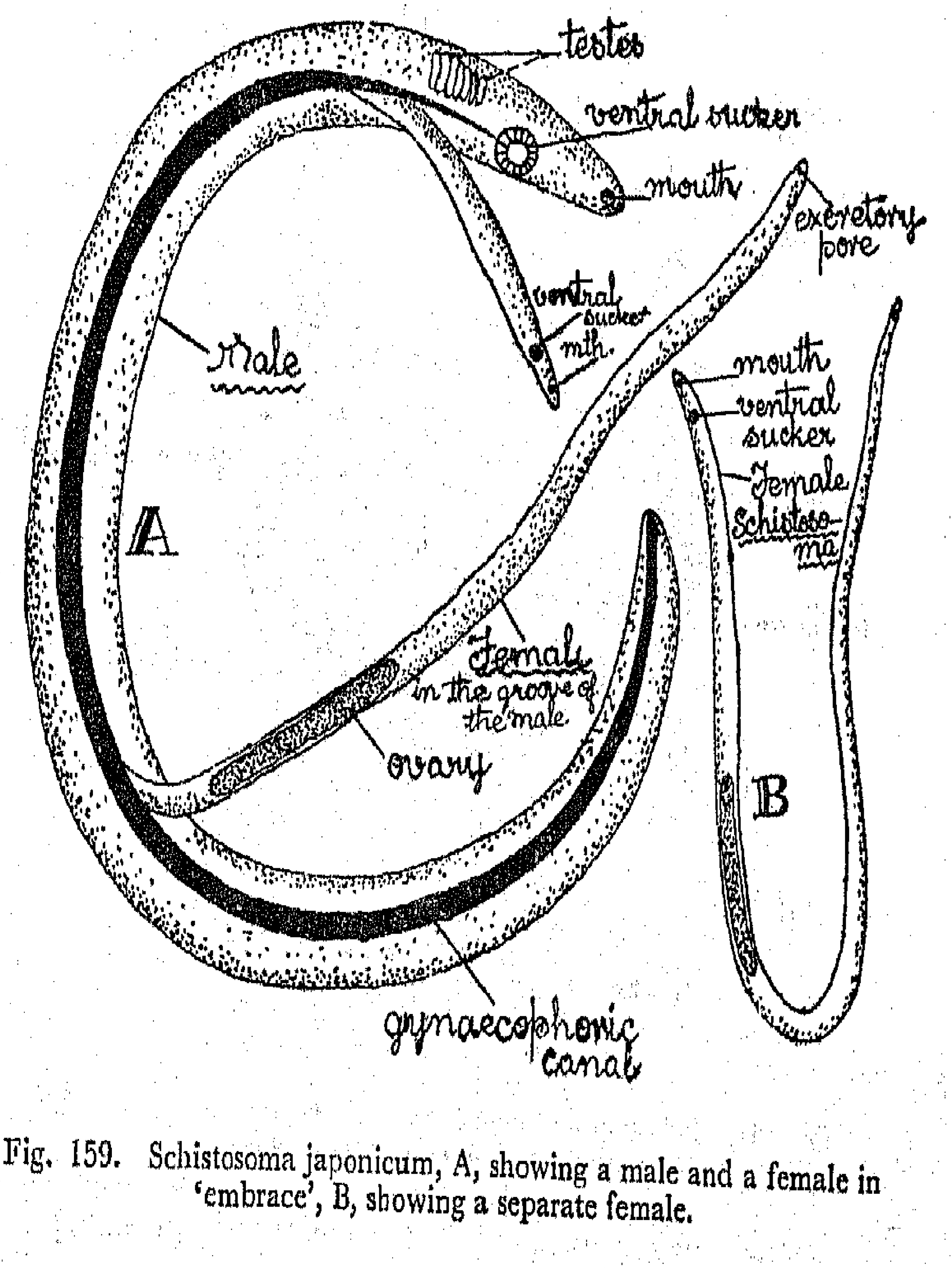

Fig. 159. Schistosoma japonicum, A, showing a male and a female in 'embrace', B, showing a separate female.

Trematoda—*Digenea*

Schistosoma (Blood-fluke) found in the portal veins of man and feeds on blood. These animals are *unisexual* unlike most of the trematodes. The ventral sucker is larger than the oral sucker. The suckers are, however, not well developed. The male is much broader than the female. The ventral body wall of the male is rolled into a *gynecophoric canal* in which the female is always carried in more or less a 'permanent embrace'. The intestine is forked, the two intestinal limbs fuse again in the posterior region. The female *Schistosoma* is very thin, narrow and elongated and its sukers are degenerated. The eggs are laid in the blood-vessels and due to their pike, they afflict wounds in the walls of the blood capillaries and pass into the urinary bladder. The urine of the infected man contains these eggs which are passed out to the exterior during urination. The *miracidium* larva is hatched outside which penetrates the secondary host, the gastropod mollusc, snails: Planorbis, Limnae etc. Inside snail, miracidium→ sporocyst→ *cercariae* which come out of the snail's body and penetrate man's skin directly. The tail of cercaria is bifurcated. Men bathing bare-footed get infection conveniently. The metacercaria formed inside man is motile and reaches the vessels of the bladder and those near the intestine. The infection causes a disease **Schistosomiasis**, the first symptom being *haematuria* (Presence of blood in urine). The infection is fatal.

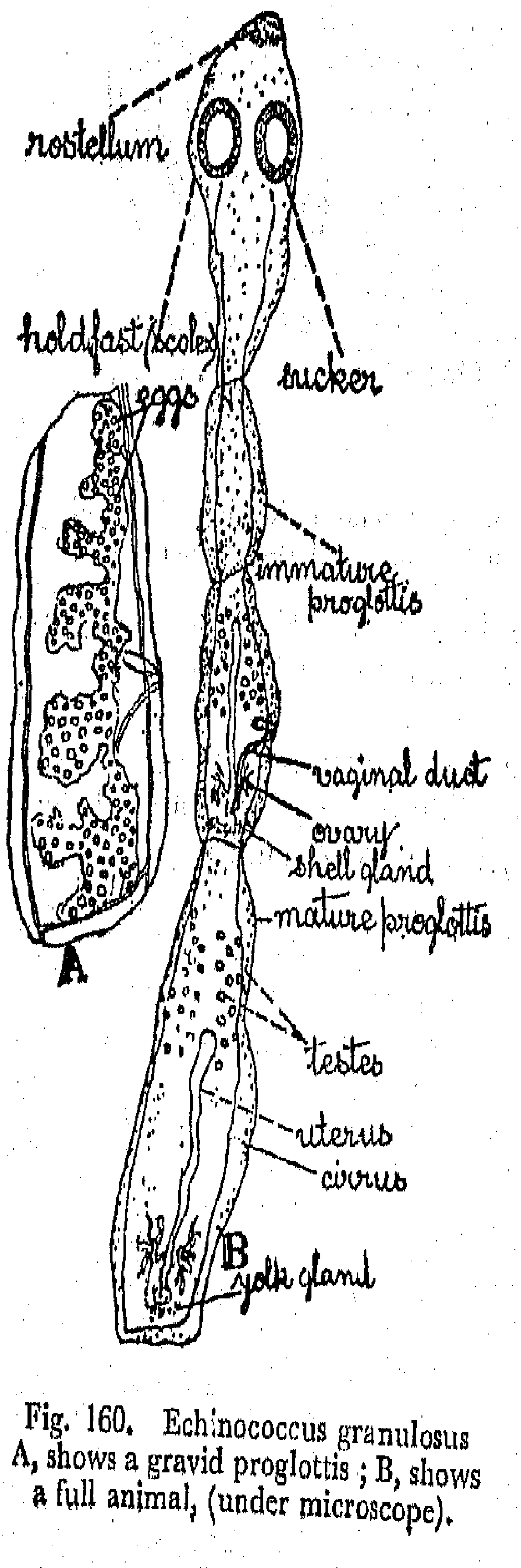

Fig. 160. Echinococcus granulosus A, shows a gravid proglottis; B, shows a full animal, (under microscope).

Cl. **Cestoda**, Subclass **Eucestoda**, Order **Cyclophyllidea**

Echinococcus granulosus has only 3 to 4 segments, is 3 to 6 m m. long; the 4th, or the last proglottis is largest and full of eggs. The adult is found in the intestine of dog. The gravid proglottides come out with the faeces of the dog and the eggs may be found on the skin of dog. Children often touch the dogs and then their own lips ; the eggs thus reach their mouth and go inside causing serious infection. From the mouth, they reach lungs, liver or brain and develop into hydatid cysts. A number of scolices are found on the cyst and the cyst multiplies. The hydatid[1] cyst may contain one gallon of fluid. A surgical treatment becomes necessary which is risky because the cyst may rupture releasing the fluid. The dogs should be kept very carefully and children should not be allowed to touch them.

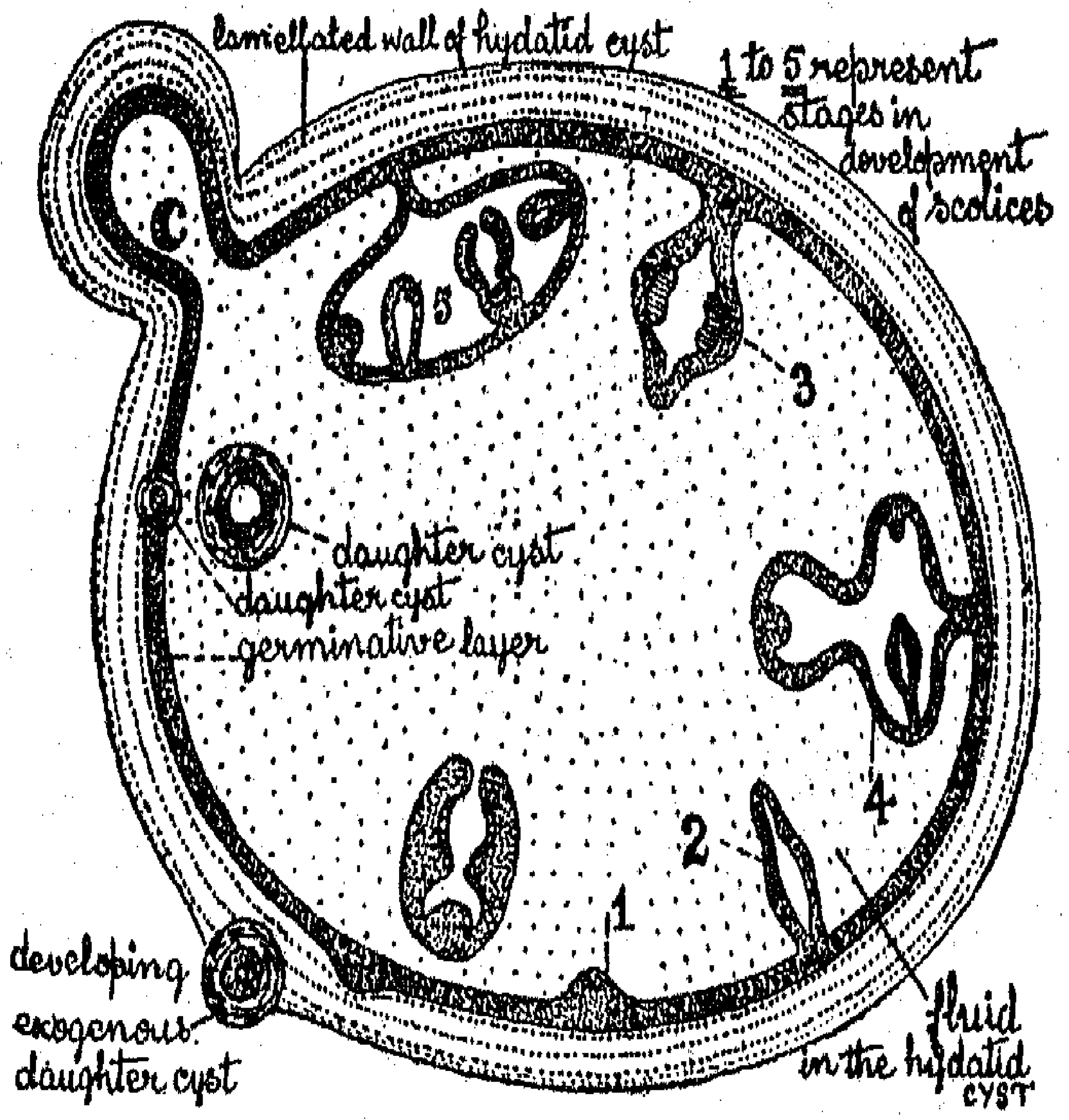
lamellated wall of hydatid cyst
1 to 5 represent stages in development of scolices
C
5
3
daughter cyst
daughter cyst germinative layer
4
2
1
developing exogenous daughter cyst
fluid in the hydatid cyst

Fig. 161. Hydatid cyst of Echinococcus granulosus showing scheme of multiplication (simplified and slightly modified after Hyman).

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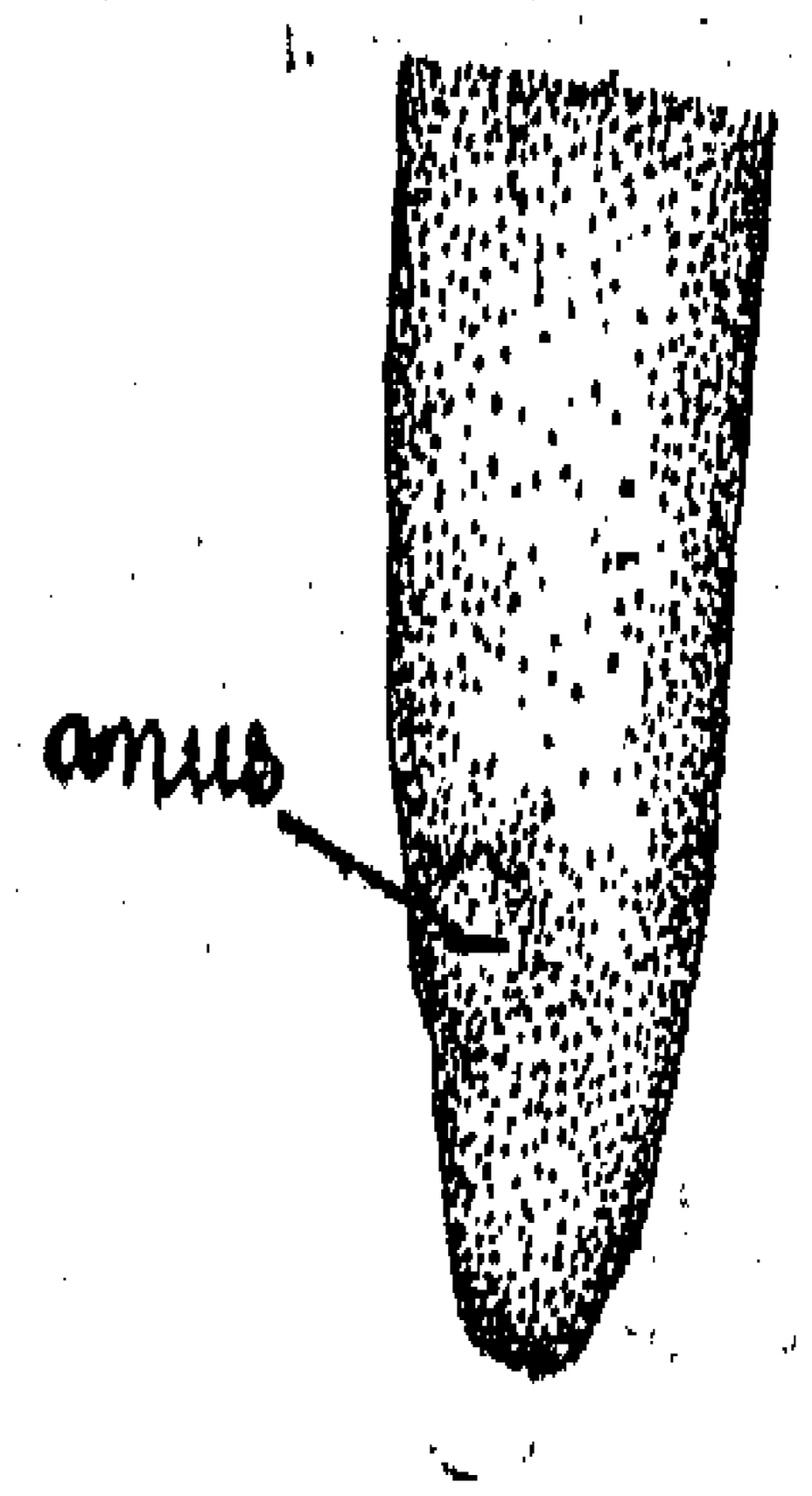
[1] [*Hydatid cyst*, in the cysticercus stage, the cyst is very large and the bladder may contain a gallon or even more of fluid, such a cyst is known as the hydatid cyst and proves fatal.]

34

Ascaris (A Nematode), Salient Features

1. **Give an account of the salient features in the anatomy of Ascaris.** (L. U., B. Sc., Prel., 1949)

2. **Describe the male and female reproductive organs of Ascaris.** (L. U., B. Sc., 1959)



Ascaris lumbricoides is a common *round worm* living as a parasite in the human intestine. The animals are unisexual, the male is considerably smaller than the female. The male has a *cloaca* but the female has *anus*. In the male the short tail is curved. From the cloacal opening of male projects out a pair of *penial setae*.

Fig. 162. Posterior end of female Ascaris lumbricoides (Redrawn after Leuckart).

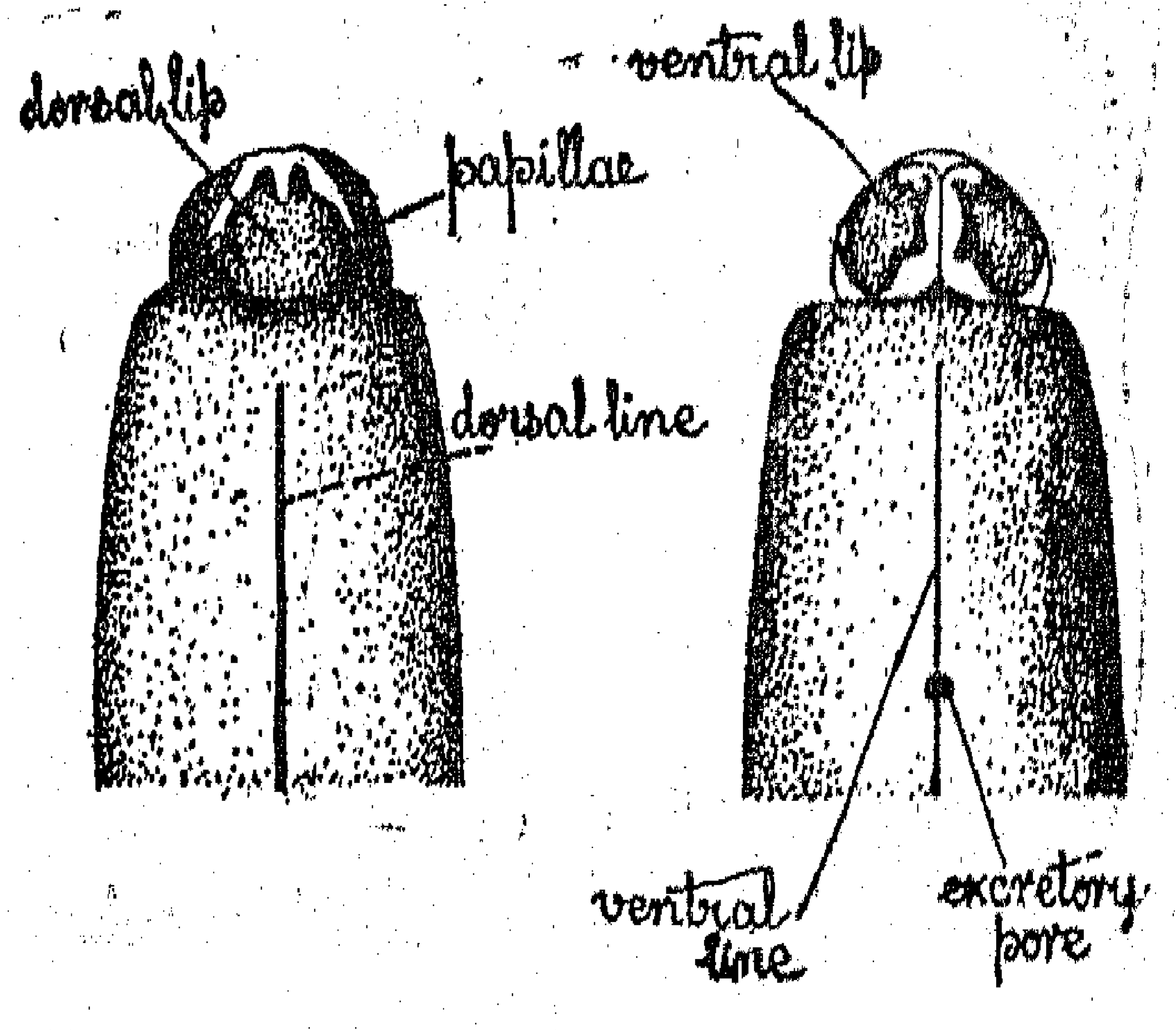


Fig. 163. Ascaris lumbricoides, anterior end ; A, dorsal view, B, ventra view. (Redrawn after Leuckart)

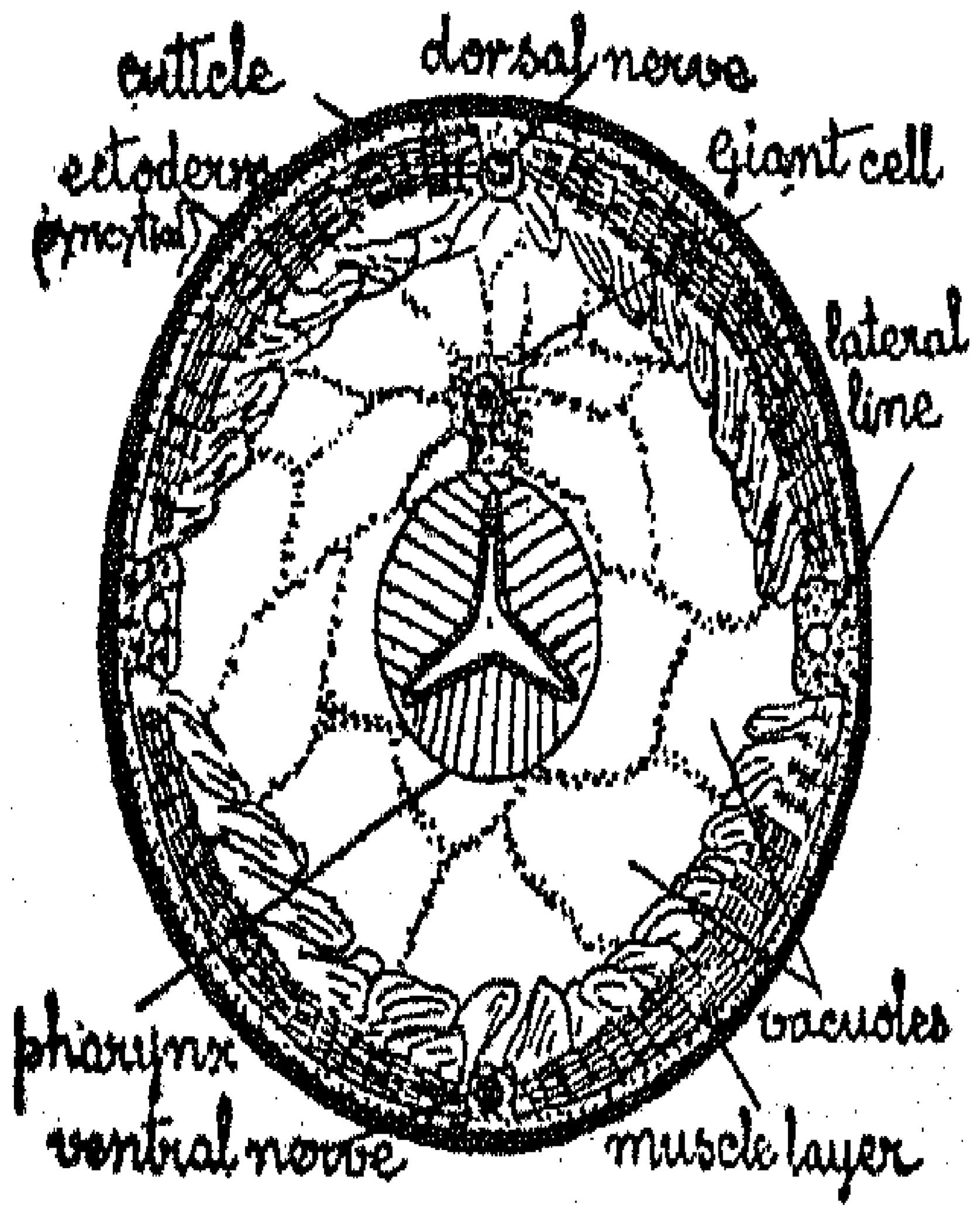


Fig. 164. Nature of pseudocoel illustrated by a schematic diagram of transverse section of Ascaris.
[Note the vacuoles which join to form the pseudocoel.]

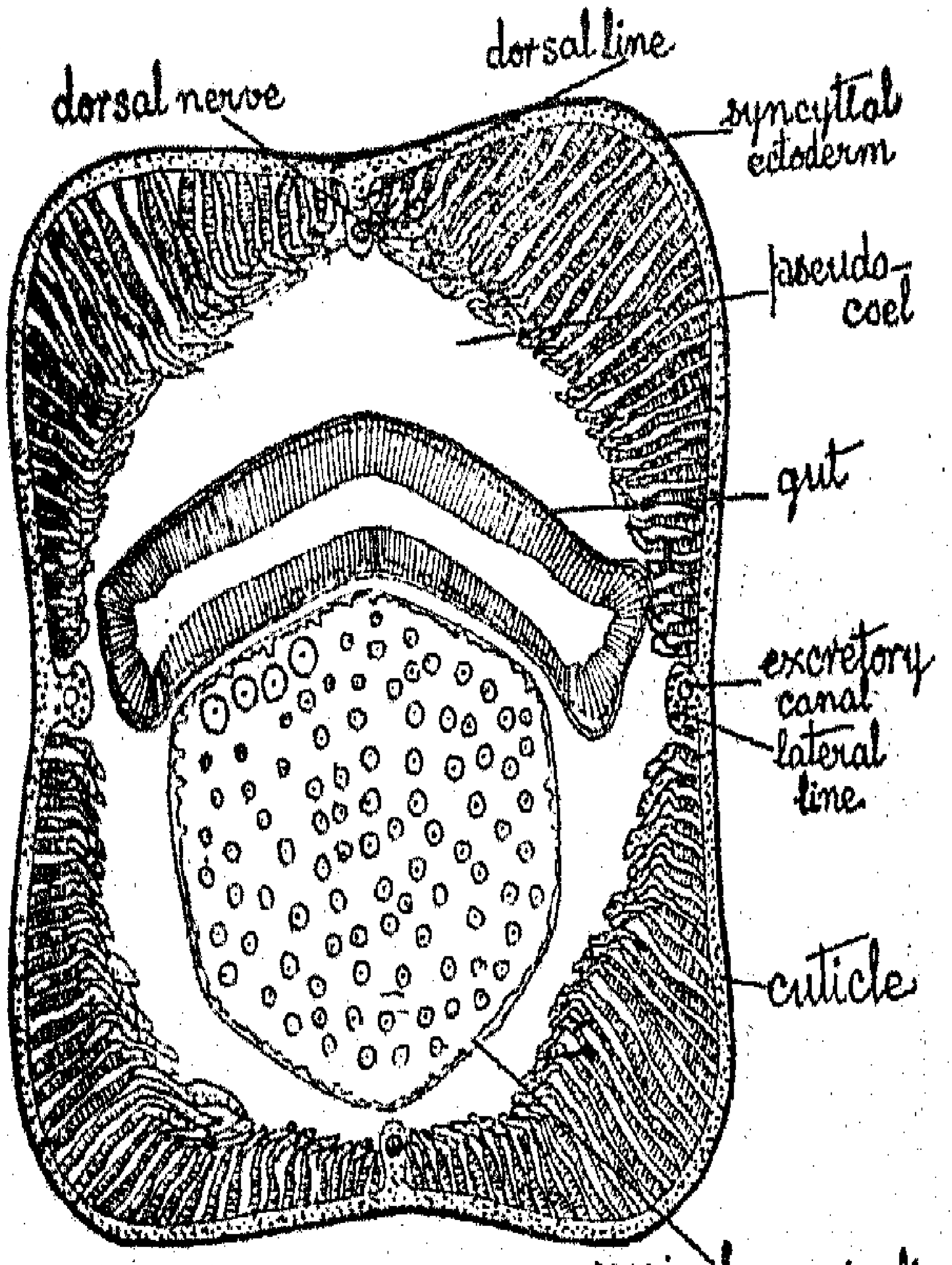


Fig. 165. Transverse section through male Ascaris in the region of vesicula seminalis.

The main features of *Ascaris* are :

1. Endoparasitic habit.

2. Unisexual nature with well developed sex organs. Males and females can be recognized by external characters.

3. The *muscle cells* have a peculiar structure with an outer *contractile* and *an inner protoplasmic part* ; the muscle layer is divided into four quadrants.

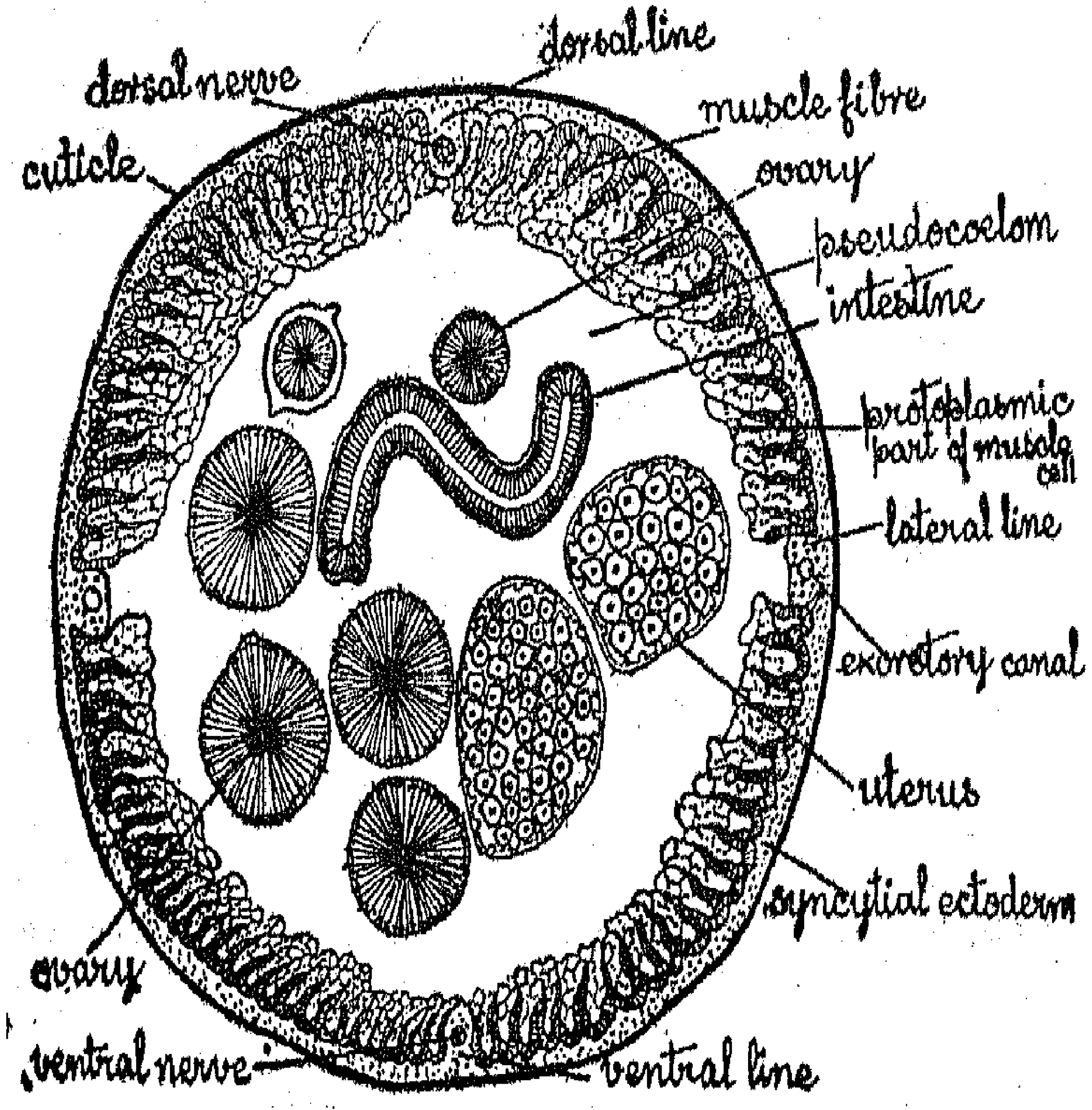


Fig. 166. Transverse section of Ascaris lumbricoides (female).

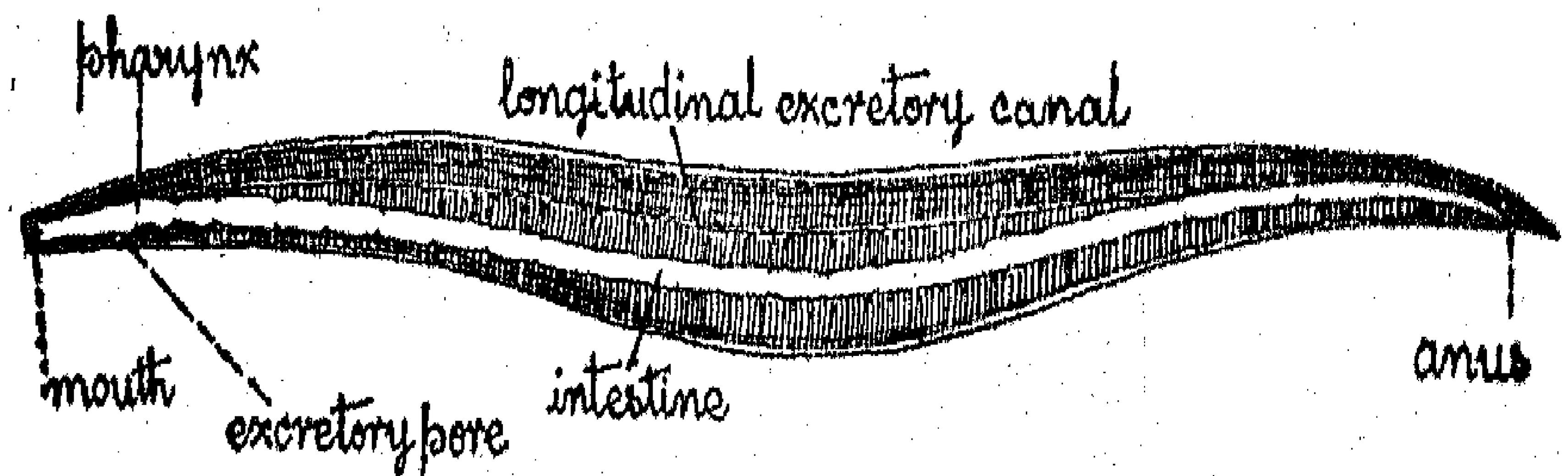


Fig. 167. Dissection of Ascaris to show the intestine.

4. Straight alimentary canal with a covering as well as a lining of cuticle; tri-radiate lumen of pharynx; absence of digestive glands.

5. Presence of an intracellular *pseudocoel* formed by fusion of the very large vacuoles of giant cell; the *body cavity* is not a true coelome, is not derived from archenteron of the embryo and is not bounded by mesodermal epithelium.

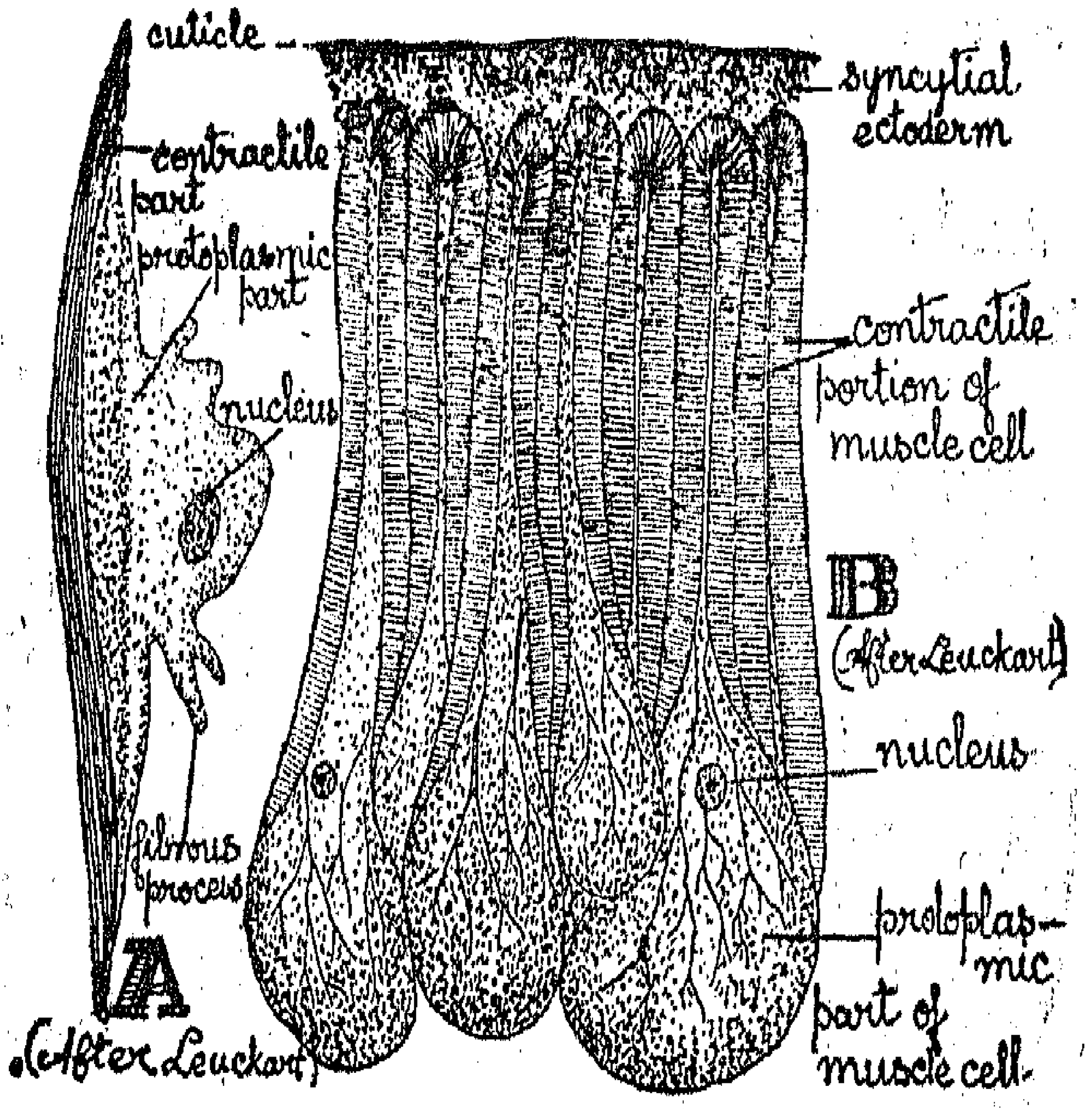


Fig. 168. A, a single muscle cell; B, several muscle cells in transverse section with portion of ectoderm below.

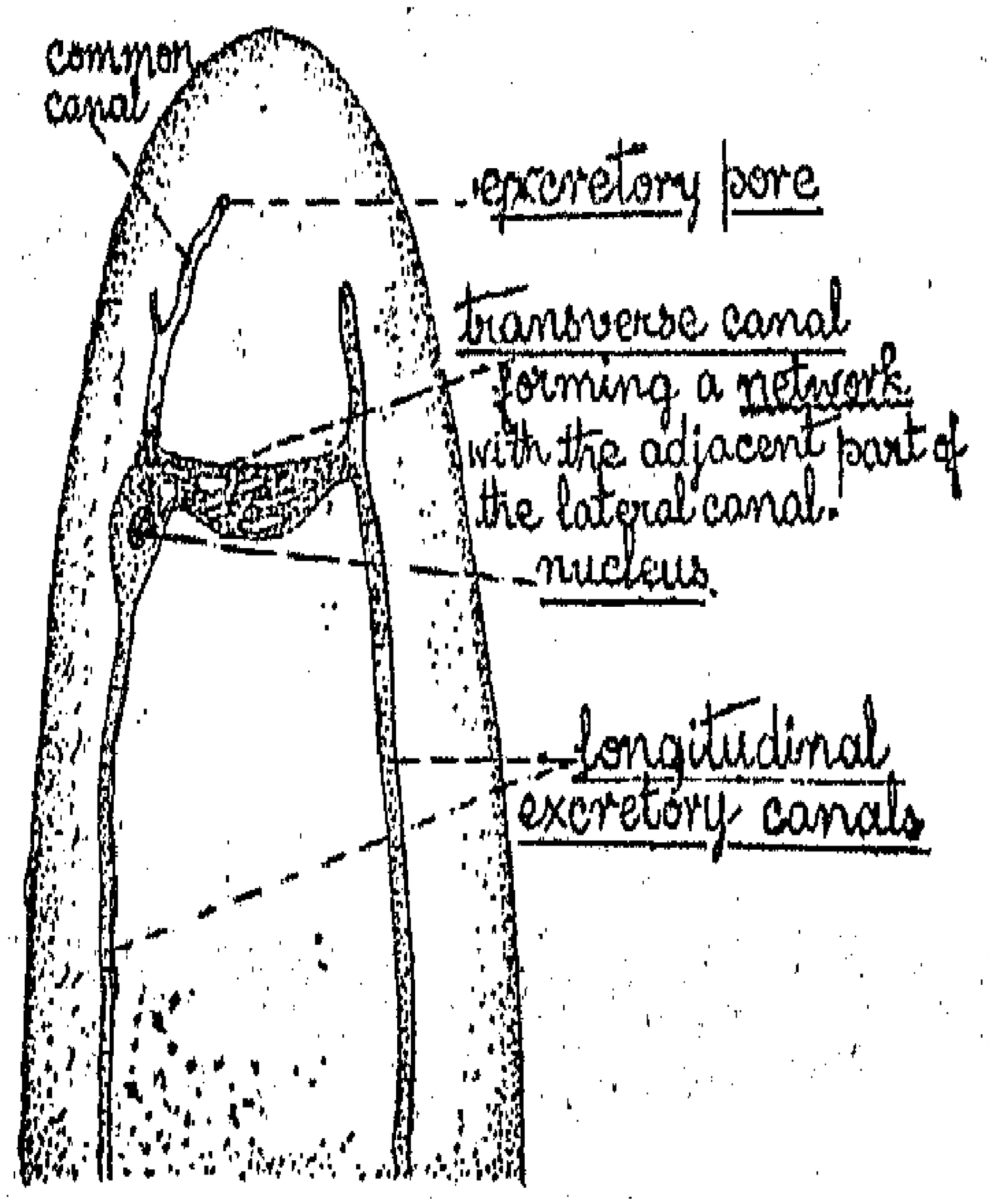

common canal
excretory pore
transverse canal forming a network with the adjacent part of the lateral canal.
nucleus
longitudinal excretory canals

Fig. 169. Excretory system of Ascaris (semidiagrammatic).

6. Absence of flame cells and cilia. The longitudinal excretory canals are excavations in a single cell of immense size.

7. Total absence of cilia. Cilia are not found in Ascaris in any part of the body at any stage.

8. The number of nerve cells is fixed; it is 162.

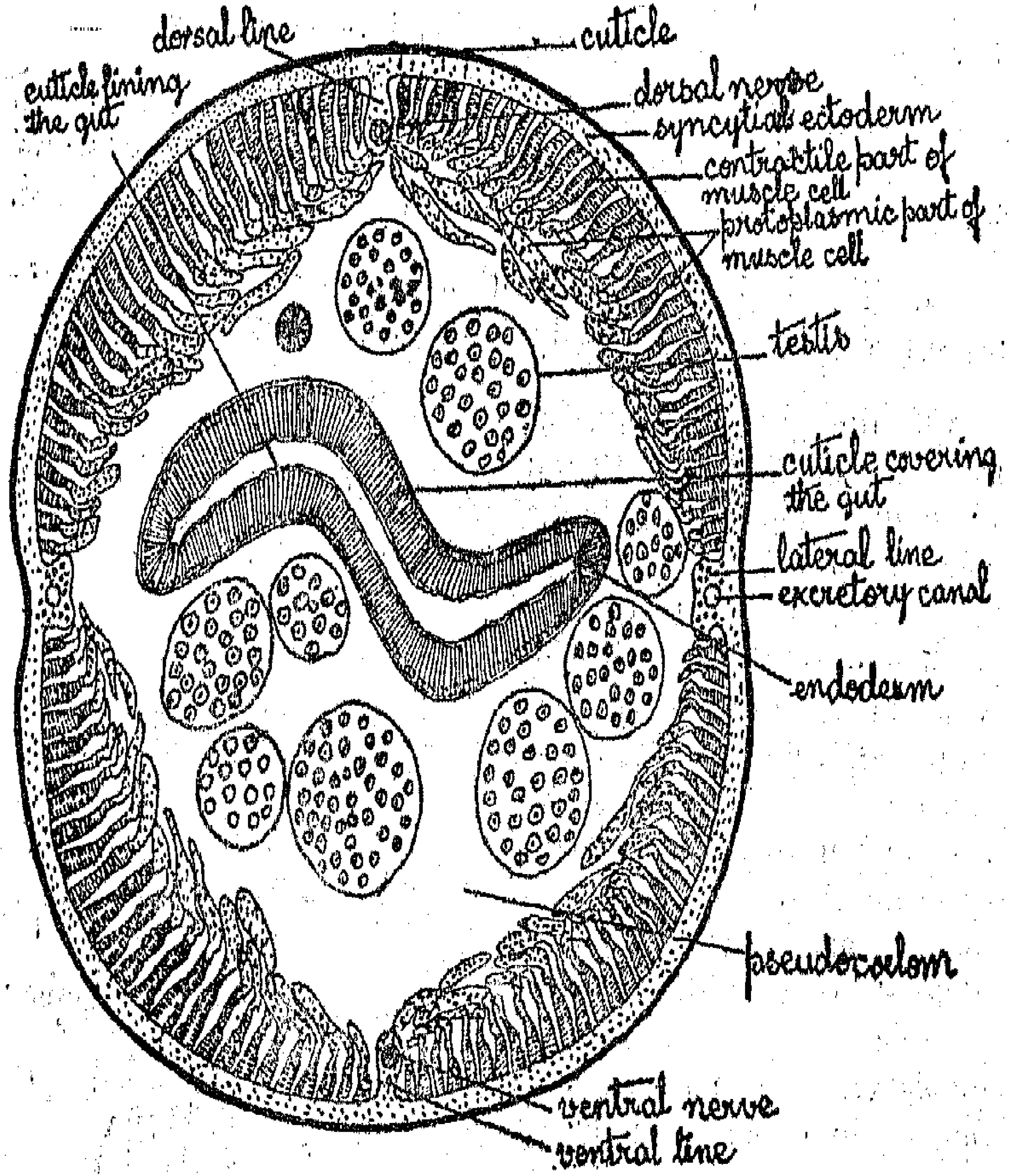


Fig. 170. Transverse section through male Ascaris (testis region).

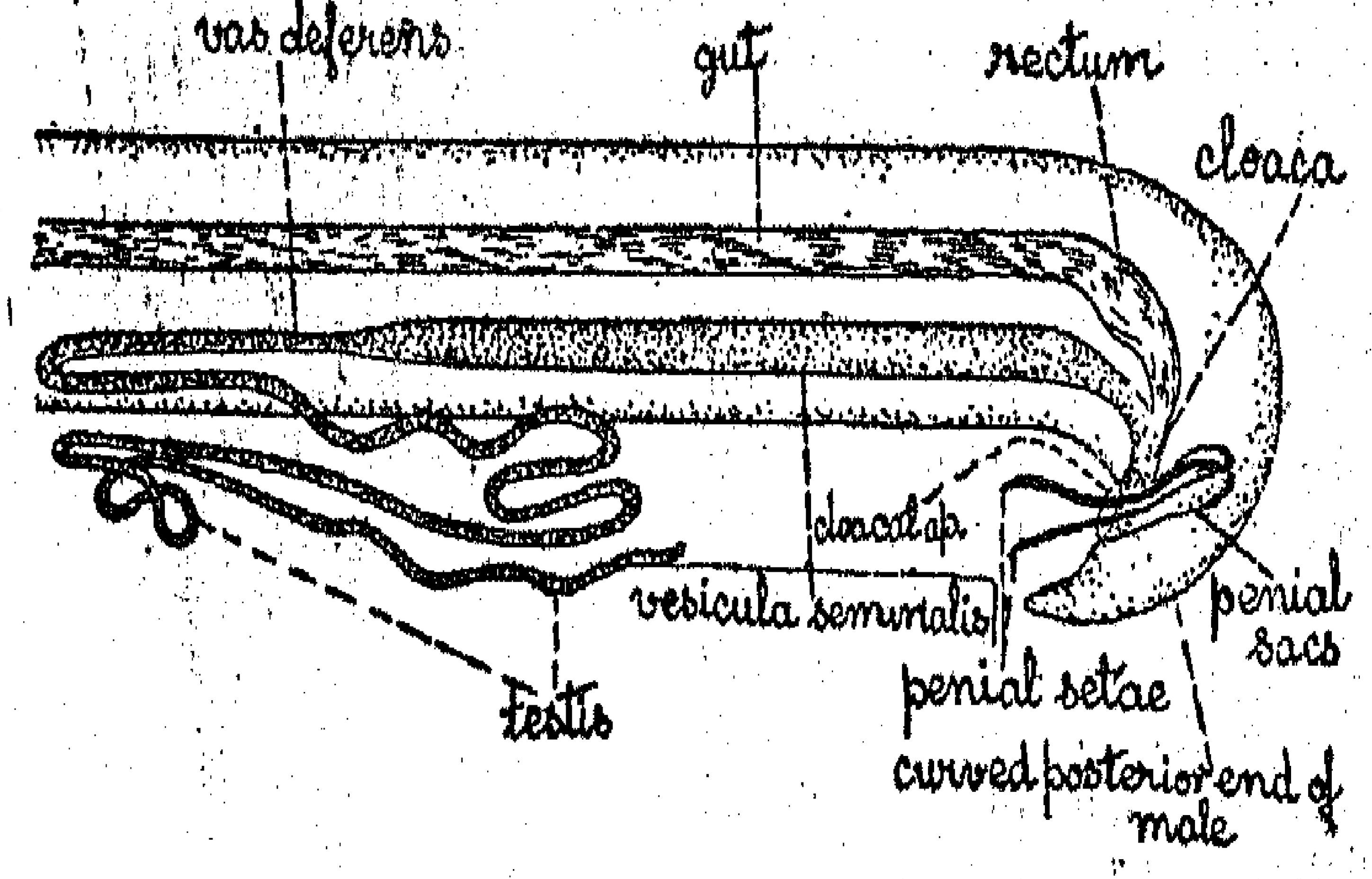


Fig. 171. Male reproductive system of Ascaris.

9. Tubular sex-organs; *tailless nonmotile sperms* which become motile only when transferred into the body of the female. Copulatory setae are found in males.

10. A very large number of eggs (**200,000** per day) are laid; the larva undergoes several moults.

11. There is no intermediate host.

12. The cells of Ascaris in general are very large; the body cavity and the excretory system have cells of immense size.

13. The syncytial ectoderm is thickened to form a *dorsal*, a *ventral* and *two lateral* lines or thickenings; these lines form the four longitudinal ridges in which the nuclei of ectoderm are found.

14. The body is covered with a delicate cuticle which shows transverse wrinkles. The body is absolutely unsegmented.

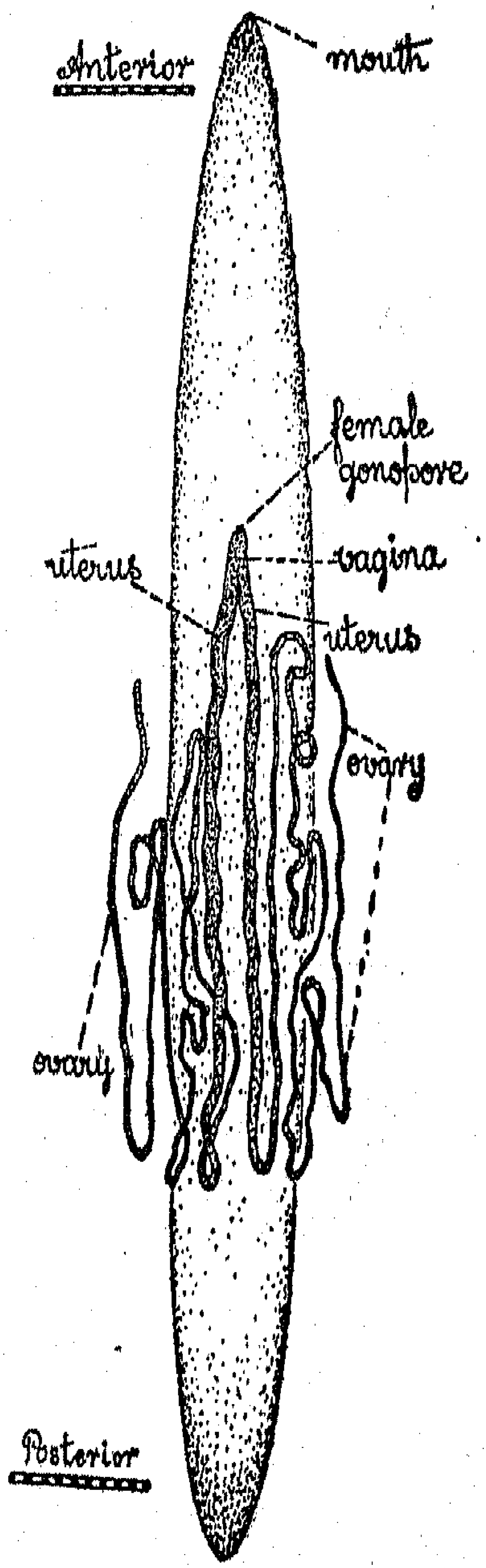


Fig. 172. Female reproductive organs of Ascaris.

Of the above, points at serials 3, 4, 5, 6, 7, 8, 9, 12 and 13 are the salient features in the anatomy of *Ascaris*.

In the male, there is a single coiled thread-like *testis* which in the anterior terminal region consists of a solid mass of generative cells but in the posterior region there is an axial cord or rachis to which the male cells are attached. Testis→vas deferens→a wide vesicula seminalis→*ductus ejaculatorious* a narrow tube opening into the rectum. Paired muscular sacs (containing copulatory penial setae) open in the dorsal wall of the rectum. The copulatory penial setae project out from the cloacal aperture (ventral). Sperms are non-motile; they become motile on reaching into the female as a result of copulation. In the **female**, there are two coiled **ovaries**→2 uteri→median vagina→opens on the ventral surface at 1/3 of the body-length from the anterior end. 200,000 eggs produced every day. Fertilization occurs in the first part of the uterus.

Fertilized eggs laid in human intestine→to exterior with his faeces→exterior (mosaic development) 9 to 13 days→coiled *first stage* **rhabditoid larva**→moults→in one week→*second stage larva* still enclosed in shell→*swallowed by men* with improperly washed or uncooked vegetables (salad etc.)→man's intestine→duodenum where a *small larva* hatches out, penetrates intestinal wall→migratory journey of about 10 days, from intestinal wall→blood capillaries→hepatic portal vein→liver→heart→lungs where the larva causes great damage, bleeding etc. may occur→alveoli of lungs (moults)→*bronchi*, trachea,→glottis→coughed into oesophagus→stomach→intestine where it moults 4th time and develops into the adult. No intermediate host is needed for the completion of the life-cycle which takes about 2 to 3 months. When found in every large number, it blocks the passage of the gut and may become fatal. Sanitary disposal of human faeces, sanitary habits and hygienical precautions in dietetics are the preventive measures. Normally, *Ascaris* is a relatively less harmful parasite.

35

Enterobius and Ancylostoma (Nematode Types)

Enterobius vermicularis (pin-worm or seat worm) is a common cosmopolitan human parasite; the adult lives in the caecum, appendix and large intestine of man. The female is 8 to 13 mm. and the male is 2 to 5 mm. in size. As the uteri of the females bulge with eggs, the worms migrate downwards to the anus and make 'regular nightly trips' deposit eggs in the region surrounding the anus in the moist grooves between the buttocks and retreat into the rectum. The creeping movement of these mature female worms in the peri-anal region of man (mostly children) particularly during the evening or at night, causes intense itching, irritation and even inflammation of anus. Often the worms penetrate into the mucosa of small intestine and the appendix where also they cause inflammation. A gravid female lays more than 20,000 eggs at a time. When due to itching the infected child (or man) rubs his anus, his hand and finger nails get the eggs which may be conveyed to his own mouth directly or indirectly. One may also get infection by ingesting eggs with raw vegetables which already have a deposit of eggs due to dirty conditions. The infection is passed on to others by the infected children. Flies etc. sitting on faeces transfer eggs to human food and drinks. Sometimes the female worms themselves are passed out with human faeces; they disintegrate and liberate their eggs which become free in the faeces and find access into human mouth.

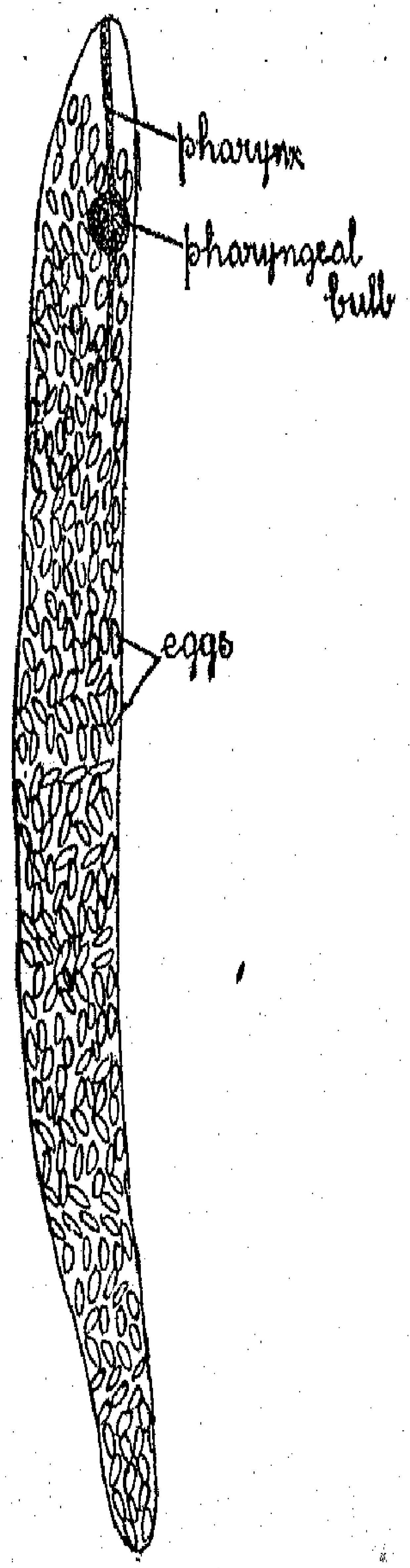


Fig. 173. Enterobius vermicularis (A gravid female).

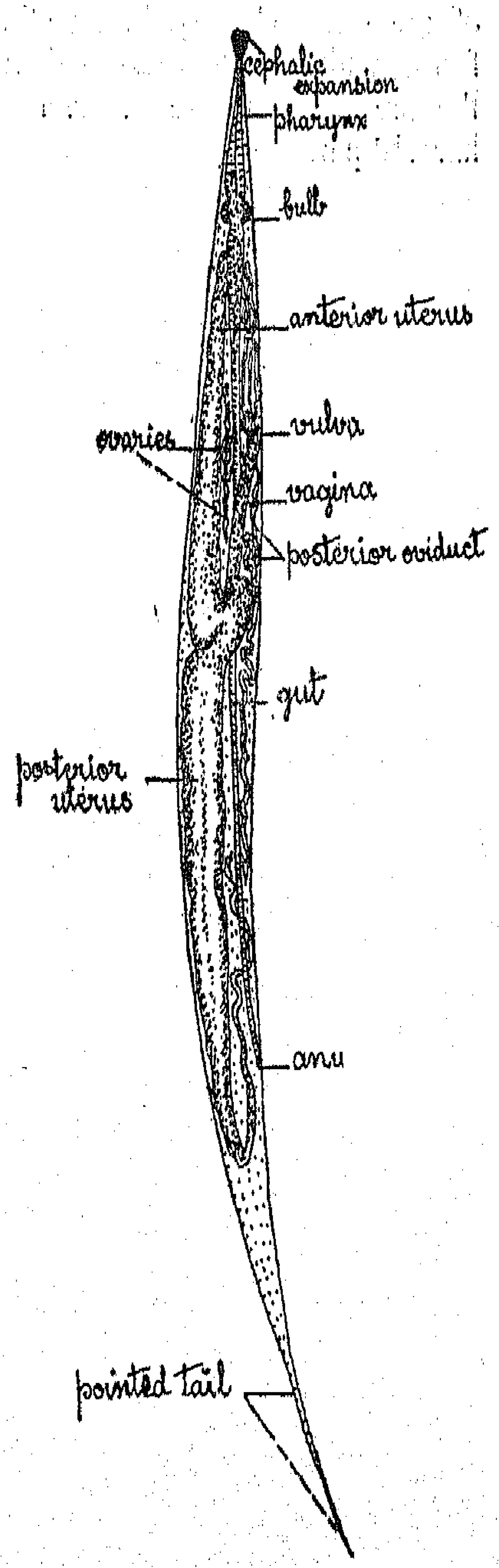


Fig. 174. Enterobius vermicularis, female.

Most characteristic anatomical feature is the presence of a *pharyngeal bulb*. The posterior end of male is curved ventrally and there is a single spicule. In the female, the tail is greatly pointed.

The first laid egg contains a larva inside the egg-shell. When swallowed, the egg hatches out in man's duodenum, a **rhabditoid larva** is produced→moults twice in the small intestine, changes into the adult which assumes sexual maturity and descends into the last part of the intestine. After fertilization, the female

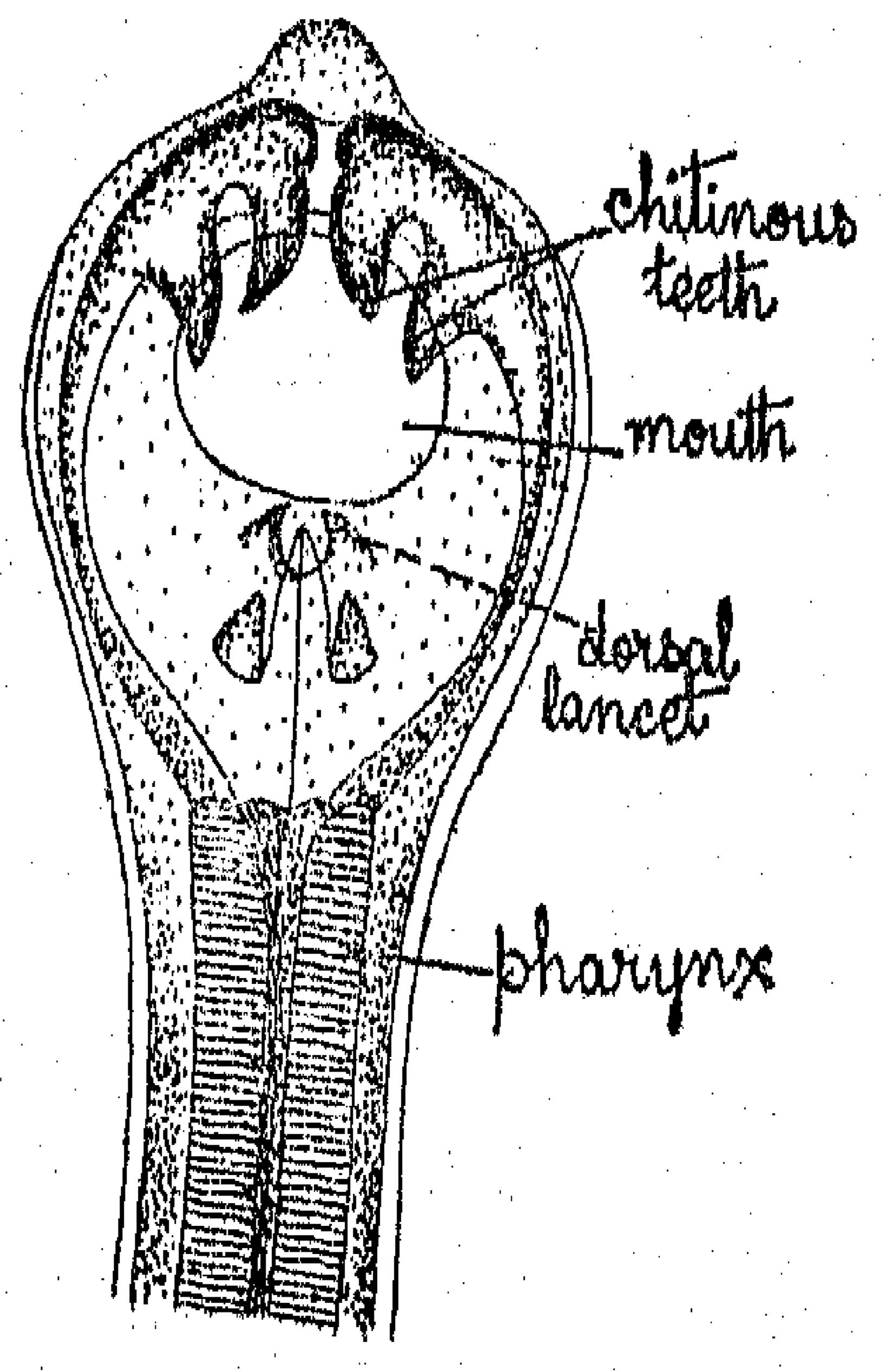


Fig. 175. Anterior end of Ancylostoma showing the buccal capsule (Based on Leuckart).

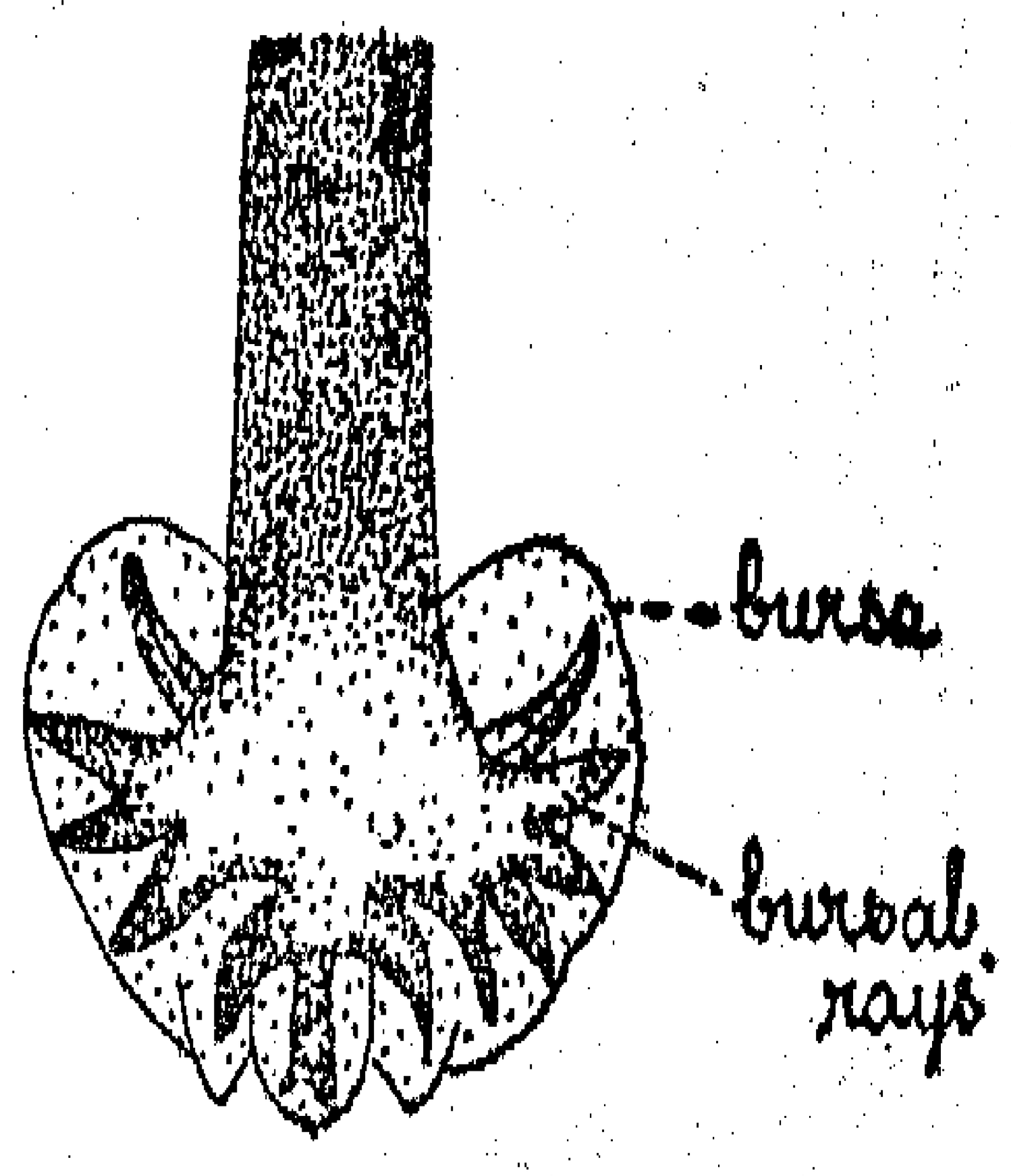


Fig. 176. Posterior end of male Ancylostoma duodenale (Redrawn after Leuckart).

becomes pregnant and deposits eggs round the anus; for this it creeps out through the anal aperture. The animal is very soft and bursts, releasing the eggs in showers. Besides troublesome itching, the parasite may cause reflex nervous symptoms due to toxins liberated by it. The disease is called the 'pinworm disease'.

Ancylostoma duodenale (Hook-Worm) (see fig. 176 and 175) is a parasite in the small intestine of man, in the duodenum or in the upper part of intestine where it remains attached to epithelium. At the anterior end, there is a buccal capsule with teeth like chitinous thickenings. The buccal capsule has two pairs of such teeth. It devours large quantities of living tissue of man and causes the **hook-worm disease.** The male has at its posterior end a wide expansion known as '*bursa*' which is supported by chitinous *bursal rays*. The posterior end of the female has no bursa. The worms draw bit by bit, the intestinal mucous membrane into their buccal capsule and nourish themselves on the blood and tissue juices. The female lays 10,000 to 20,000 eggs per day.

The eggs are passed outside with the faecal matter; the larva hatches and moults twice; is exceedingly active, pierces through man's skin and reaches his blood system; the infection is thus direct without any intermediate host. The larva reaches the venous system→heart→pulmonary artery→lungs capillaries→cavities of lungs→trachea→with cough→glottis→oesophagus→intestine where the larva develops into the adult. Due to the migration of larva, the skin and lungs become inflammated. The patient becomes more susceptible to tuberculosis. In the hook-worm disease, the patient suffers from anaemia. The parasite injures the intestinal epithelium and the infection hampers physical and mental development of children.

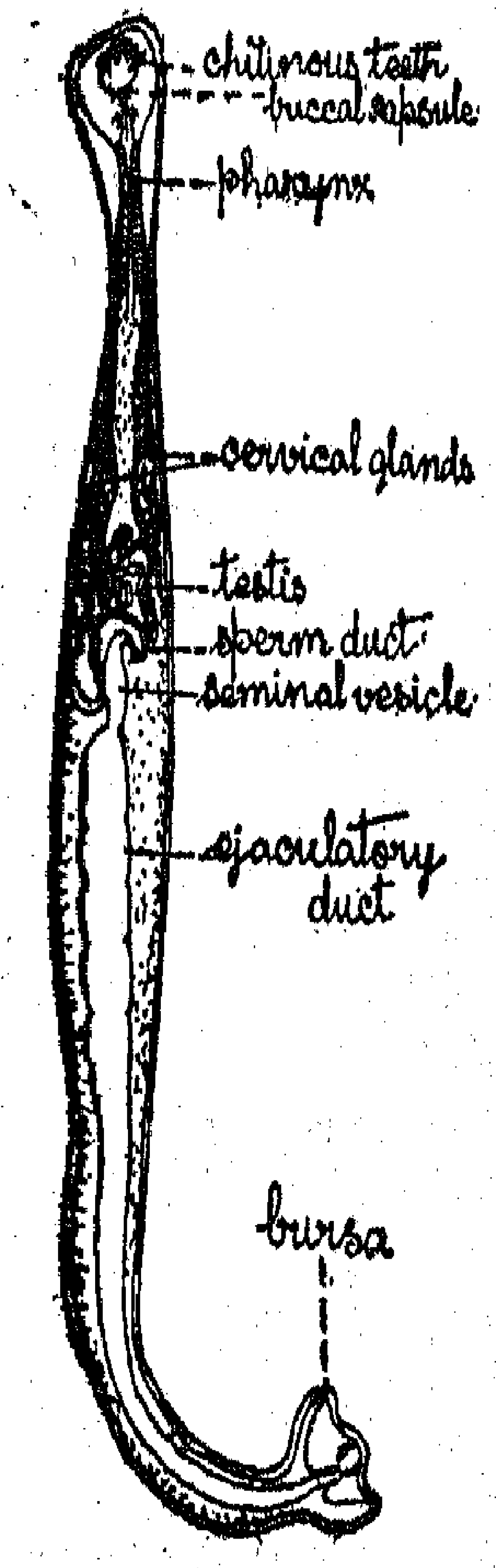


Fig. 177. Ancylostoma duodenale (Male specimen).

36

Characters of the Phylum Annelida

The characteristic features of Annelida are:

1. Triploblastic, bilaterally symmetrical, elongated worms.
2. True coelom found.
3. True metamerism.
4. A distinct blood vascular system with distinct blood vessels+.
5. The nervous system typically consists of a cerebral ganglion, oesophageal connectives and a double ventral ganglionated nerve cord. A pair of ganglia is present in each segment.
6. The excretory organs are metamerically repeated *nephridia* or *segmental organs*; the *coelomoducts*, united with nephridia or separate from them, serve for the passage of generative elements to the outside.
7. The body wall is muscular with an *external circular layer* in which the muscle cells are arranged with their longitudinal axes across the worm's width and an *internal longitudinal layer* in which the muscle cells have their axes disposed parallel to the length of the animal.
8. The larva when found is a free-swimming ciliated *trochophore*.

37

Nereis, A Polychaete Annelid Worm

1. **Make a labelled sketch of the following:**

(a) **T. S. of *Nereis* through the middle of body.**

(L. U. B. Sc., Prel., 1956)

2. **Make a labelled diagram of T. S. of *Nereis* passing through Parapodium.** (L. U. B. Sc., Prel, 1958)

3. **Illustrate by means of diagrams the structure of *Nereis*. Add a note on (i) Parapodia (ii) Heteronereis and (iii) Receptor organs.**

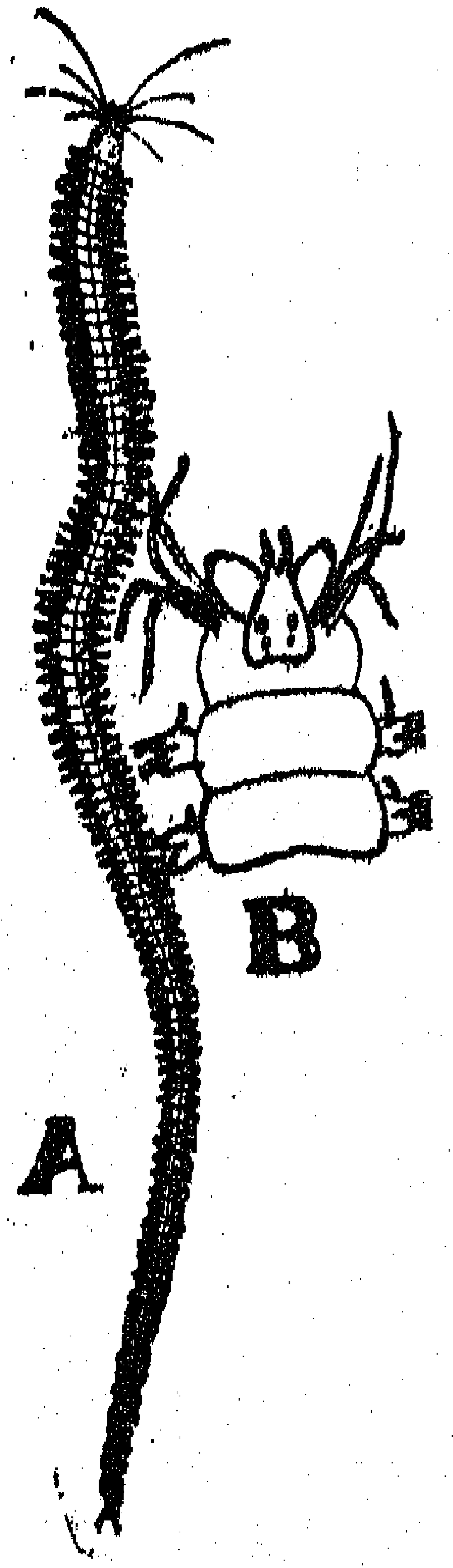


Fig. 178. Nereis; A, the entire worm; B, the head and two segments.

Nereis is a polychaete worm inhabiting burrows in the sand or mud of the sea-shores, between tide-marks, among the sea-weeds or under stones. The entire body is divisible into (i) *head* and (ii) *trunk*. The head consists of a *prostomium* bearing 4 eyes and a *peristomium* representing 2 fused segments. The trunk has about 80 segments. The prostomium bears a pair of *palpi* besides a pair of tentacles. The peristomium bears four tentacles on either side but no parapodia.

(i) The **parapodia** (See fig. 187 and 189) are muscular processes bearing bundles of setae; and a pair of parapodia are found on each trunk segment (except the anal segment). These special muscular processes are locomotory in function and assist in creeping, acting as a 'series of oars' for propelling the animal through the water. Each parapodium has two main divisions i. e. it is a biramus structure; these two divisions are (i) a dorsal *notopodium* and (ii) a ventral *neuropodium*. The *notopodium* as well as *neuropodium* are further divided into several lobes each of which bears a bundle of setae. The setae are stout chitinous rod like structures. On the dorsal and ventral sides of the parapodium are found a *dorsal cirrus* and a *ventral cirrus* each of which is a short cylindrical appendage. The setae are found in bundles; one bundle projects from the notopodium and one from the neuropodium. Each bundle of setae is lodged in a sac formed by an invagination of the epipermis known as the setigerous sac. The bundles of setae can be protruded or retracted and turned to some extent in various directions by strands of muscular fibres. Each bundle of

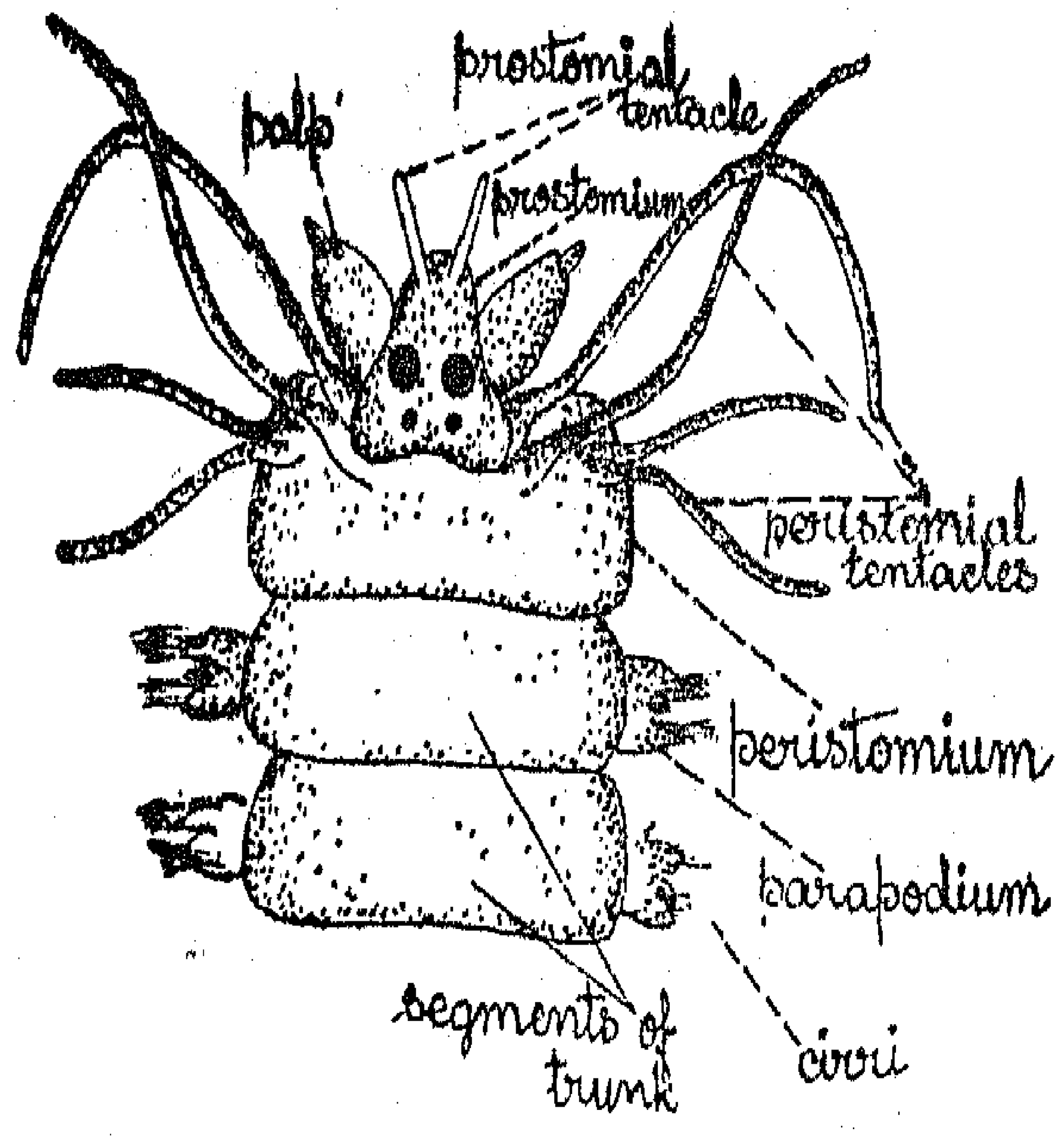


Fig. 179. Nereis showing head and two trunk segments (Dorsal view).

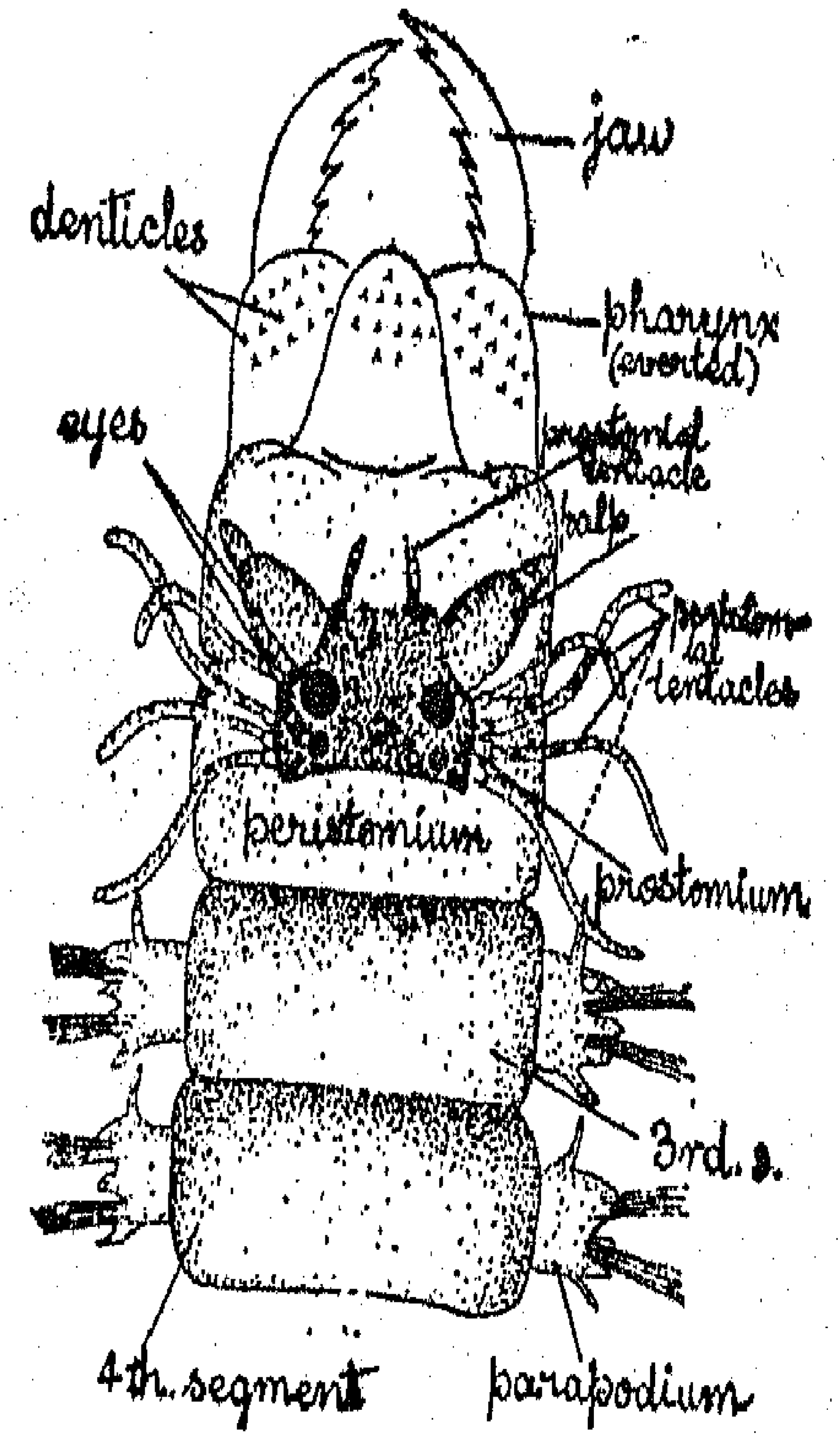


Fig. 180. Everted pharynx of Nereis with jaws.

setae has a straight, thick, pointed and dark coloured seta known as *aciculum* which furnishes skeletal support to the parapodium.

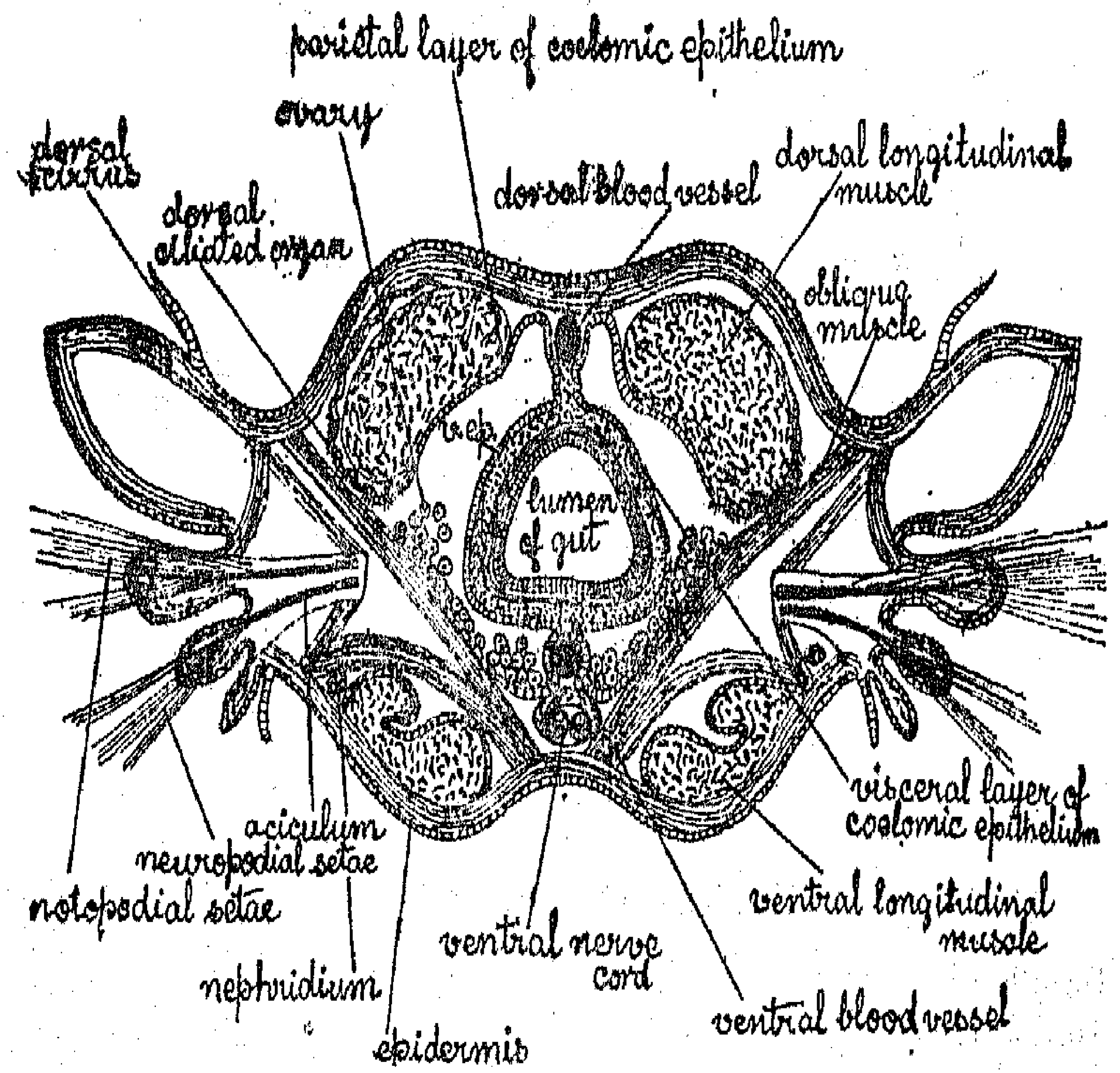


Fig. 181. T. S. of Nereis passing through parapodium.

The ordinary fine setae act as minute 'paddles' during locomotion. Each parapodium is provided with a 'complicated musculature' which controls movements of the different parapodial lobes as well as the bundles of setae. These parapodial muscles are modified circular muscles of the body wall and their most prominent group is that which originating from the circular muscles of the body-wall around the base of parapodium becomes inserted in the base of the setigerous sacs of the acicula; these muscles are called the *protractors* of the acicula, for, when these contract the acicula and the central lobes of the parapodium protrude out. Muscles in the parapodia other than the protractors function as retractors and their contraction causes retraction of the parapodium. The complex muscular equipment of the parapodium assists in its varied movements performed during the swimming and creeping movements of the worm.

(ii) Most species of *Nereis* have a sexual form known as *Heteronereis.* The development and proliferation of the sex cells is accompanied with certain characteristic changes in the structure of the posterior half of the worm in which the sex cells are particularly abundant. Thus, immediately before attaining sexual maturity *Nereis* undergoes a series of changes and becomes transformed into *Heteroneries* which represents the *sexual form,* a second phase of *Nereis.* The eyes become enlarged, the lobes of the parapodia become larger und foliaceous; longer, more numerous and oar shaped setae become developed in the parapodial lobes and the peristomial cirri become more prominent.

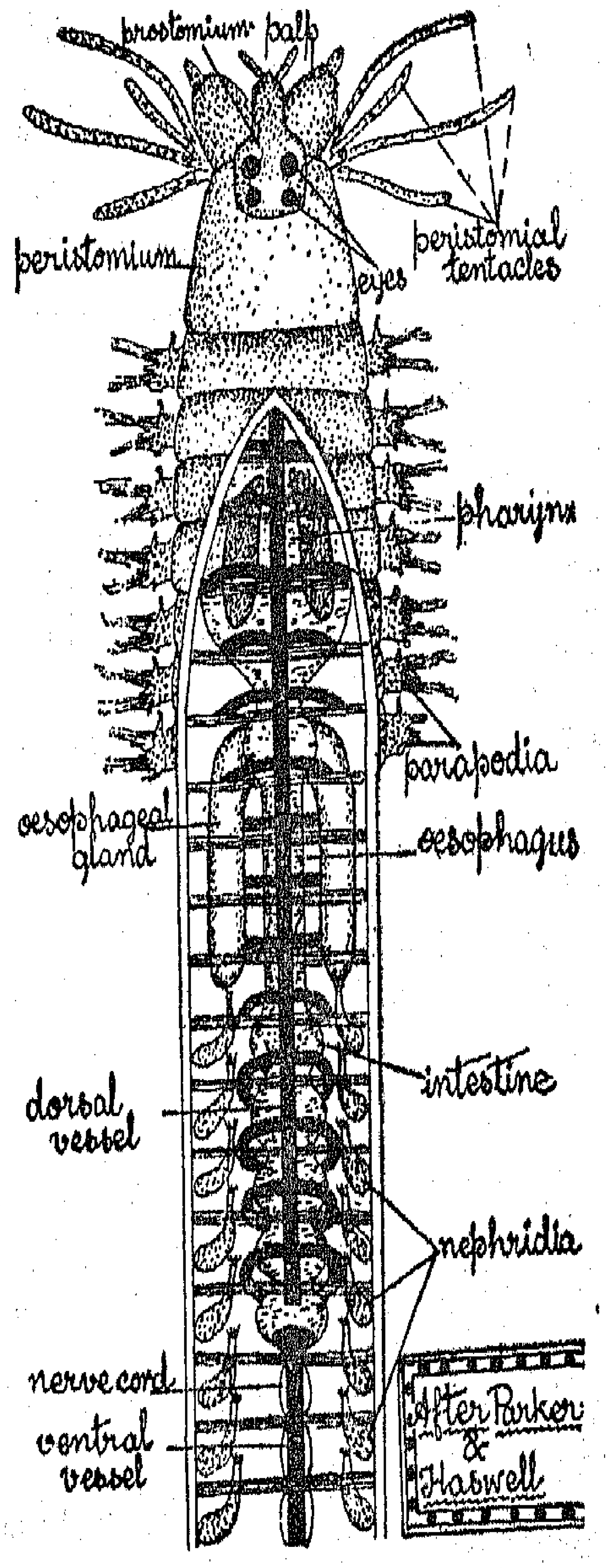


Fig. 182. Dissection of Nereis, dorsal body wall removed.

Nereis usually creeps about on the bottom but the *Heteronereis* swims about actively in water by the wriggling body movements assisted by 'paddling movements of the foliaceous parapodia with their long oar like setae'. The Heteronereis now becomes sexually mature and produces ova and sperms which differ considerably from those of the *Nereis phase.*

(ii) **Receptor organs** of *Nereis* include (i) *tactile receptors* e. g. tentacles, palpi and cirri (ii) olfactory receptors e. g. the nuchal organs and (iii) *photo-receptors,* the eyes.

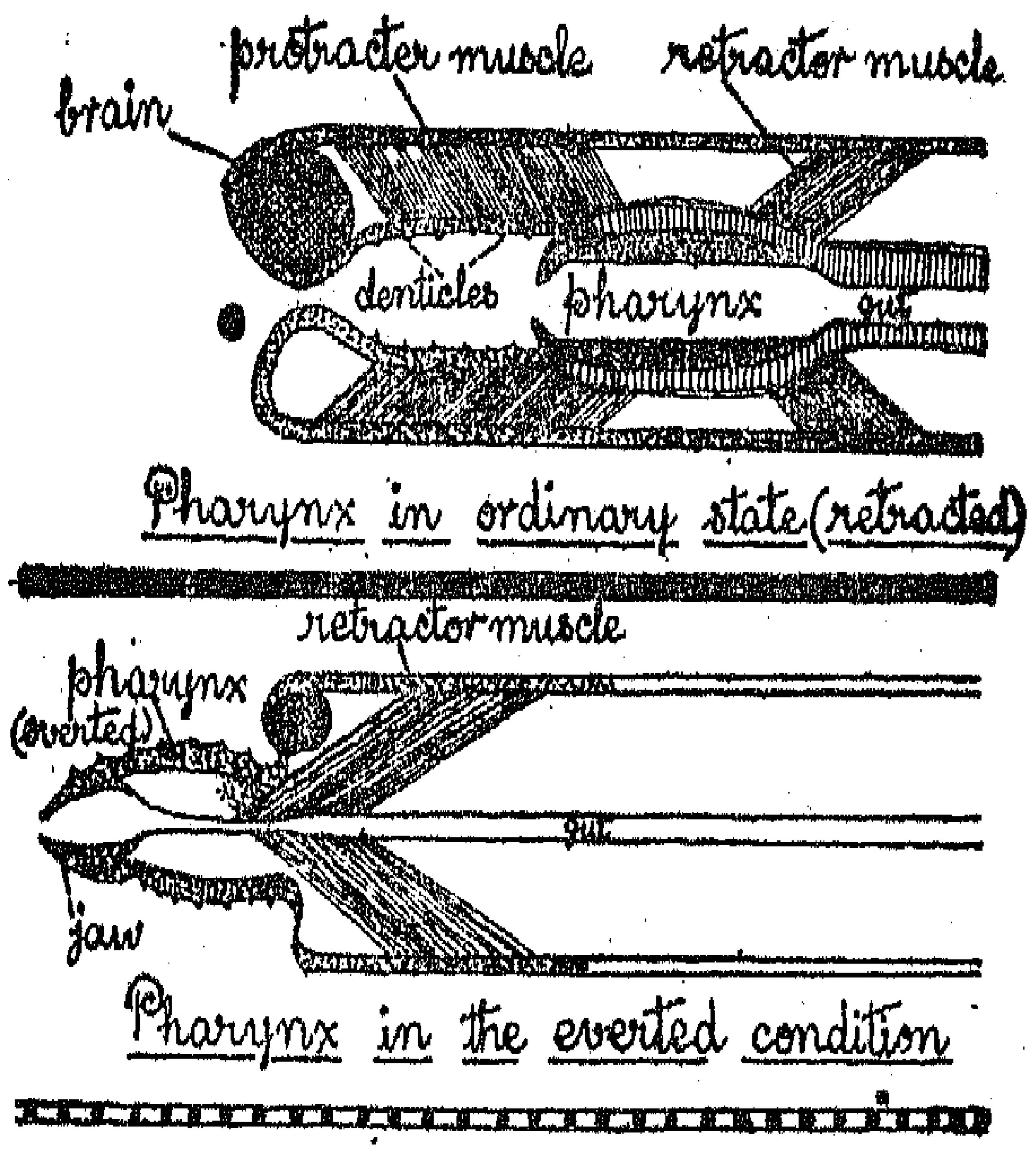


Fig. 183. Protracted and retracted pharynx of Nereis.

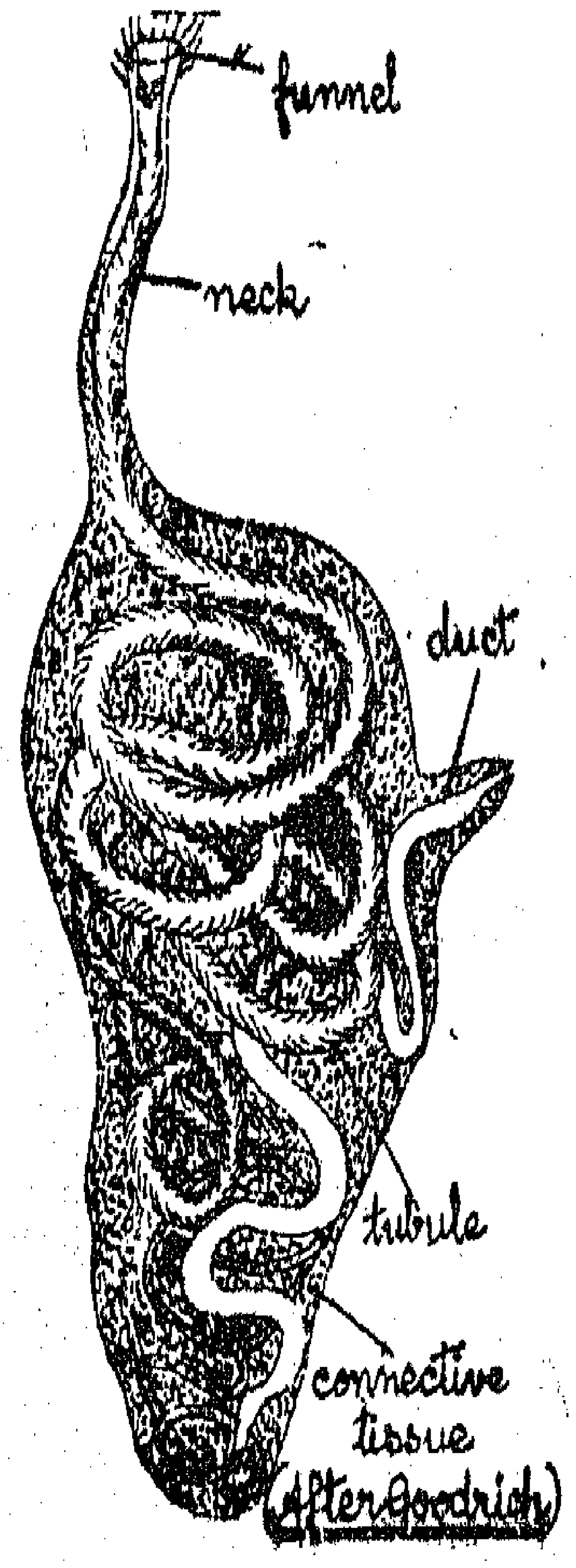


Fig. 184. Nephrium of nereis.

(i) The *tactile receptors* include a pair of *prostomial tentacles,* four pairs of peristomial tentacles and a pair of stout *palpi* borne laterally on the prostomium. The cirri are present on the parapodia (*dorsal cirrus* and *ventral cirrus*) ; the anal segment also bears a pair of *anal cirri.* All these are the organs of sense of touch. (See fig. 179).

(ii) The *olfactory receptors* are a pair of *nuchal organs,* situated in close contact with the posterior part of the brain near the posterior part of the prostomium on the dorsal side. Each nuchal organ is a *pit* lined by ciliated epithelium with gland cells.

(iii) The *photoreceptors* (See fig. 190) consist of *four simple eyes* situated on the dorsal side of the prostomium, arranged in two pairs. Each eye is formed of an ectodermal vesicle containing a cuticular lens. The ectodermal cells of the wall of the vesicle form the visual elements : the *retinal cells.* The eye consists of a darkly pigmented cup known as the retina which has a small rounded opening, the *pupil.* The retinal cup encloses a gelatinous *lens.* A dark pigment is found in the *long and narrow cells* of the retinal cup ; the outer ends of the retinal cells are modified to form *nerve fibres* which converge and get concentrated to form the optic nerve. The portion of these cells facing the lens forms clear hyaline *rods.* The epidermis and the cuticle of the general body surface pass over the eye and form the transparent *cornea.*

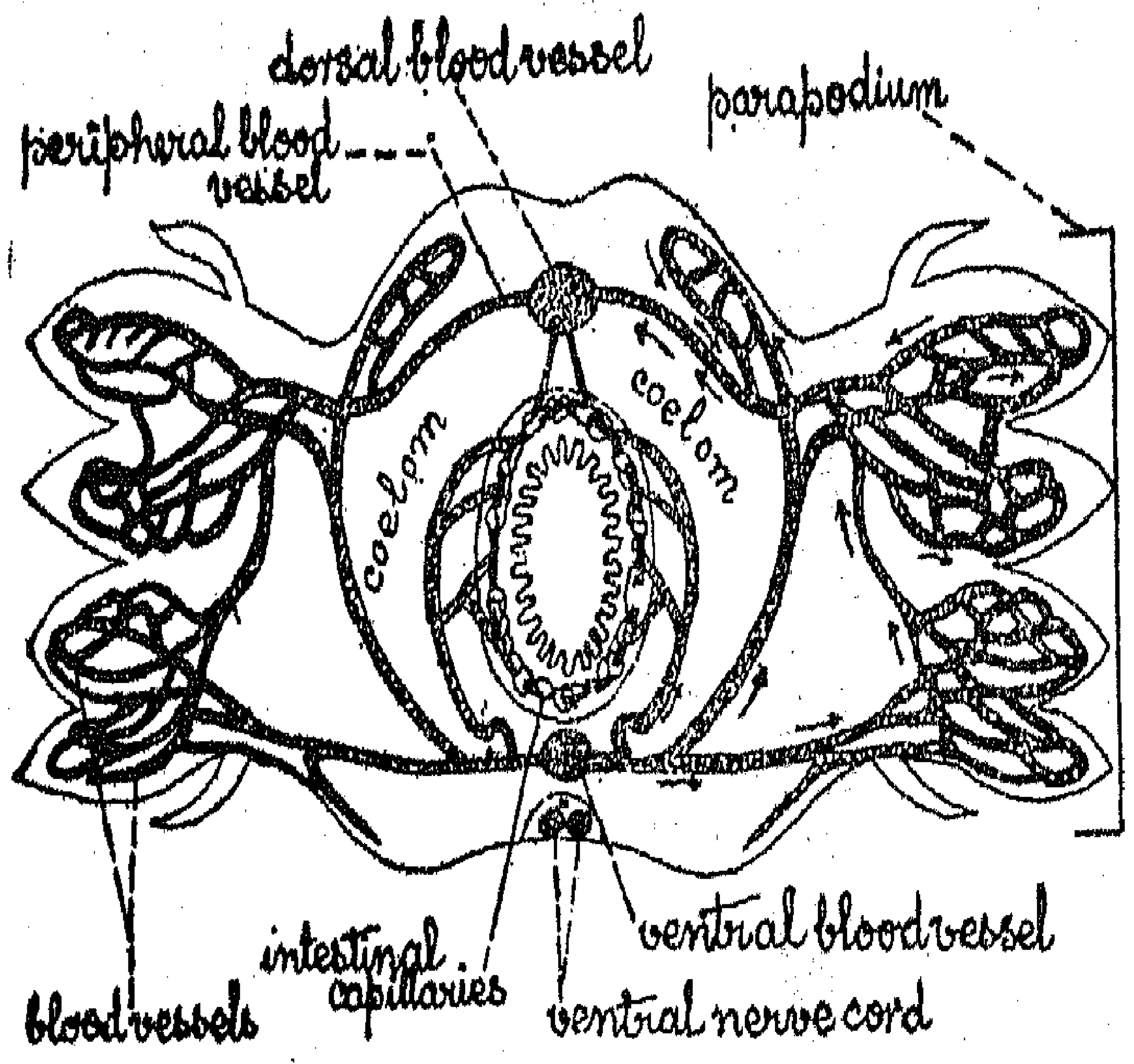


Fig. 185. Diagram showing chief blood vessels as seen in a transverse section of Nereis. (Diagrammatic)

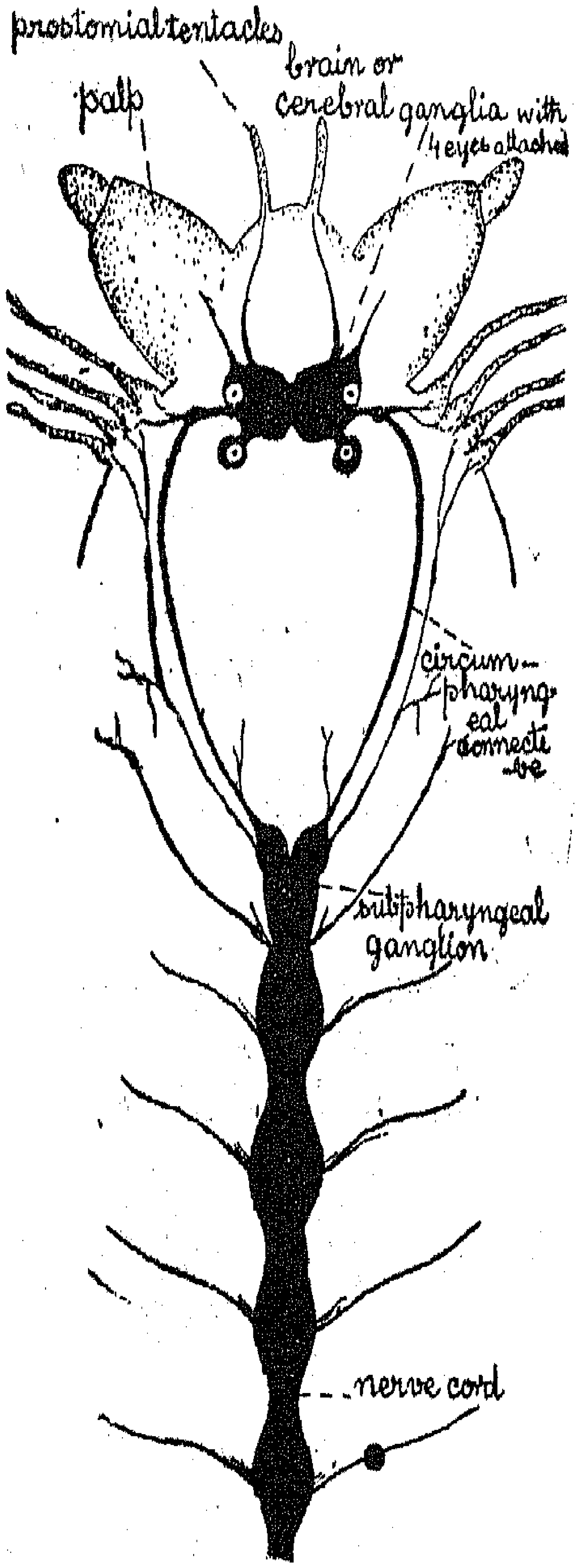
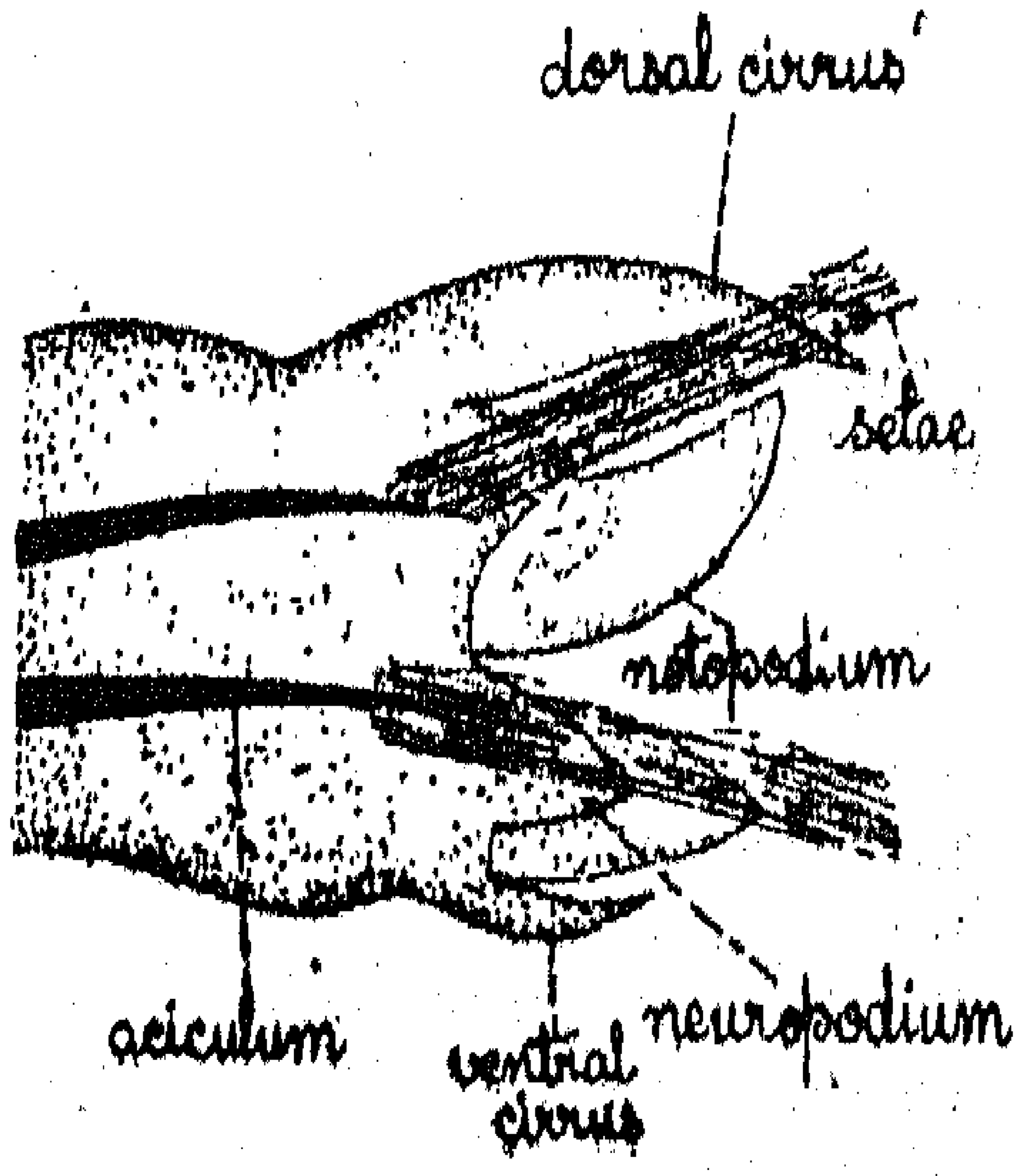

prostomial tentacles
palp
brain or cerebral ganglia with 4 eyes attached
circum-pharyngeal connective
subpharyngeal ganglion
nerve cord

Fig. 186. Anterior part of the nervous system of Nereis.

Fig. 187. Parapodium of Nereis.



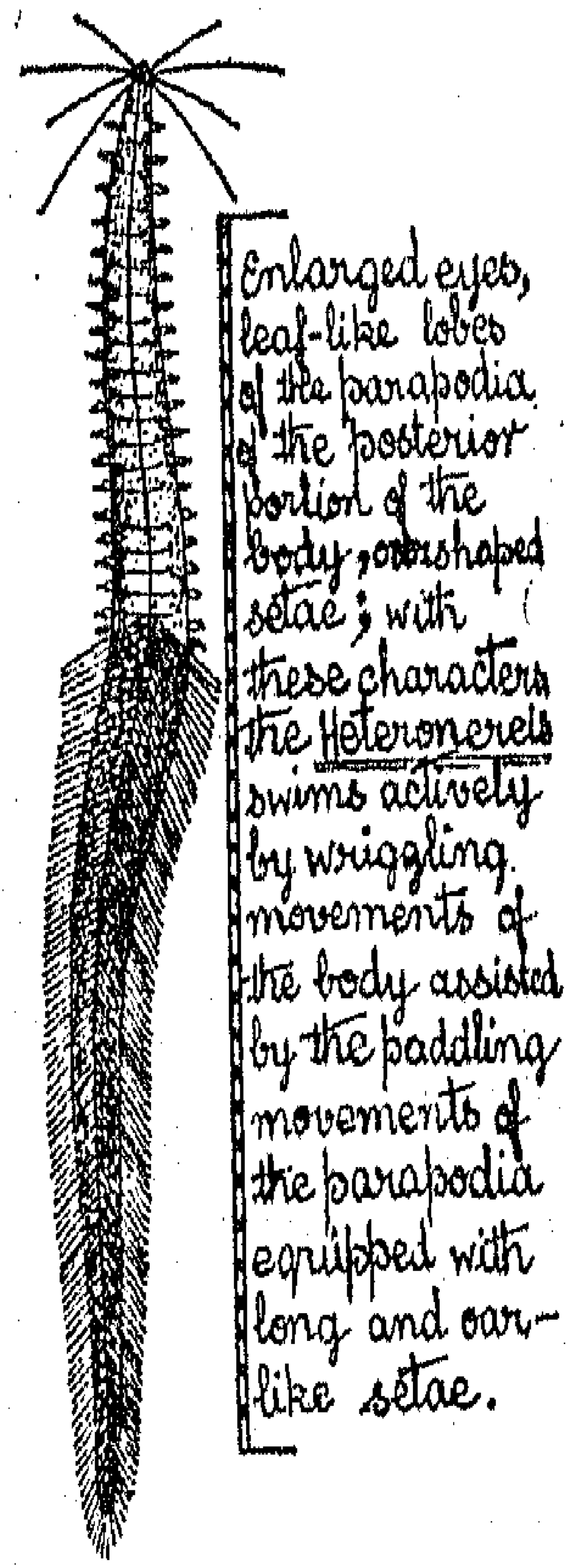

Enlarged eyes, leaf-like lobes of the parapodia of the posterior portion of the body, oar-shaped setae; with these characters the Heteronereis swims actively by wriggling movements of the body assisted by the paddling movements of the parapodia equipped with long and oar-like setae.

Fig. 188. Heteronereis.

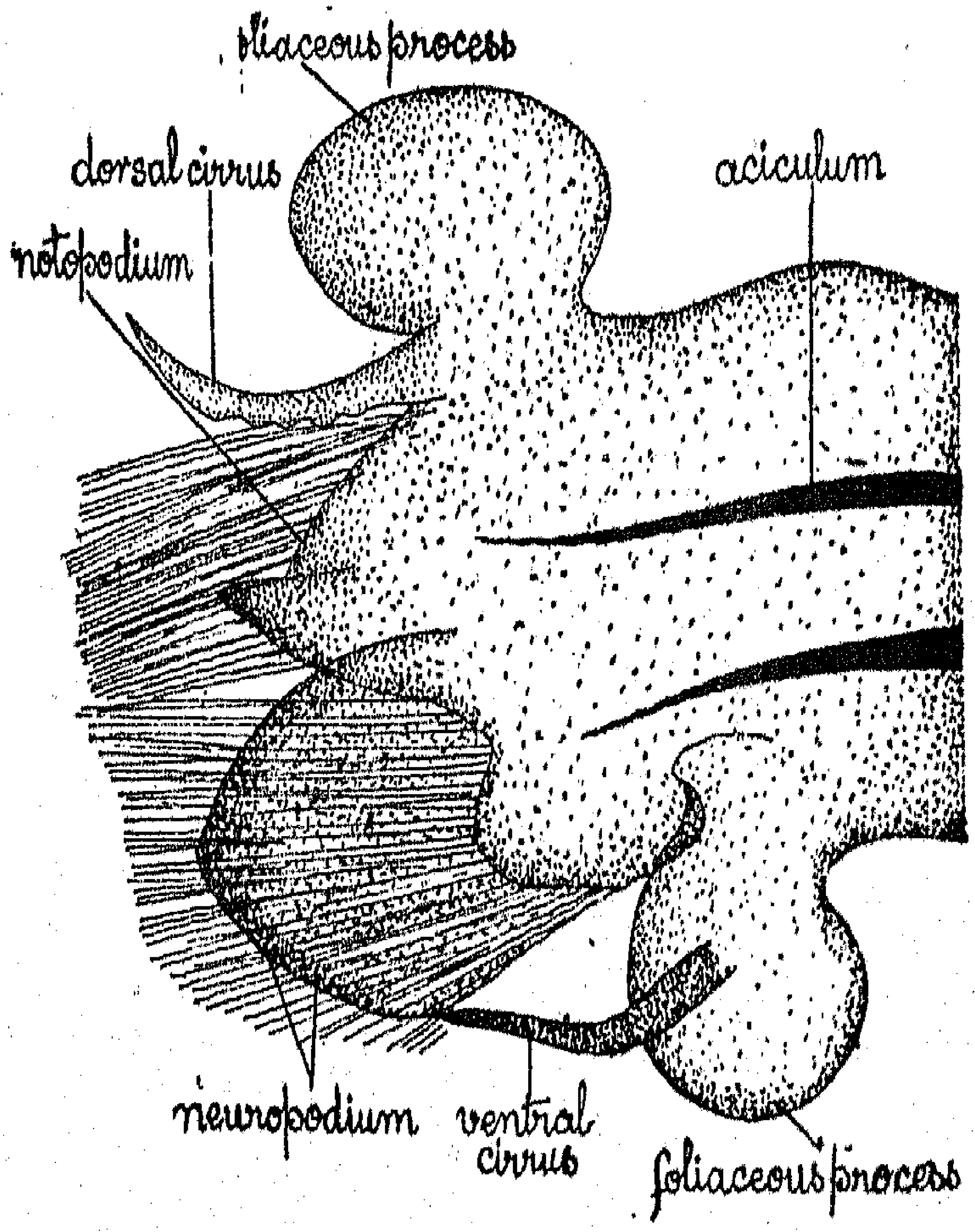


Fig. 189. Parapodium of Heteronereis.

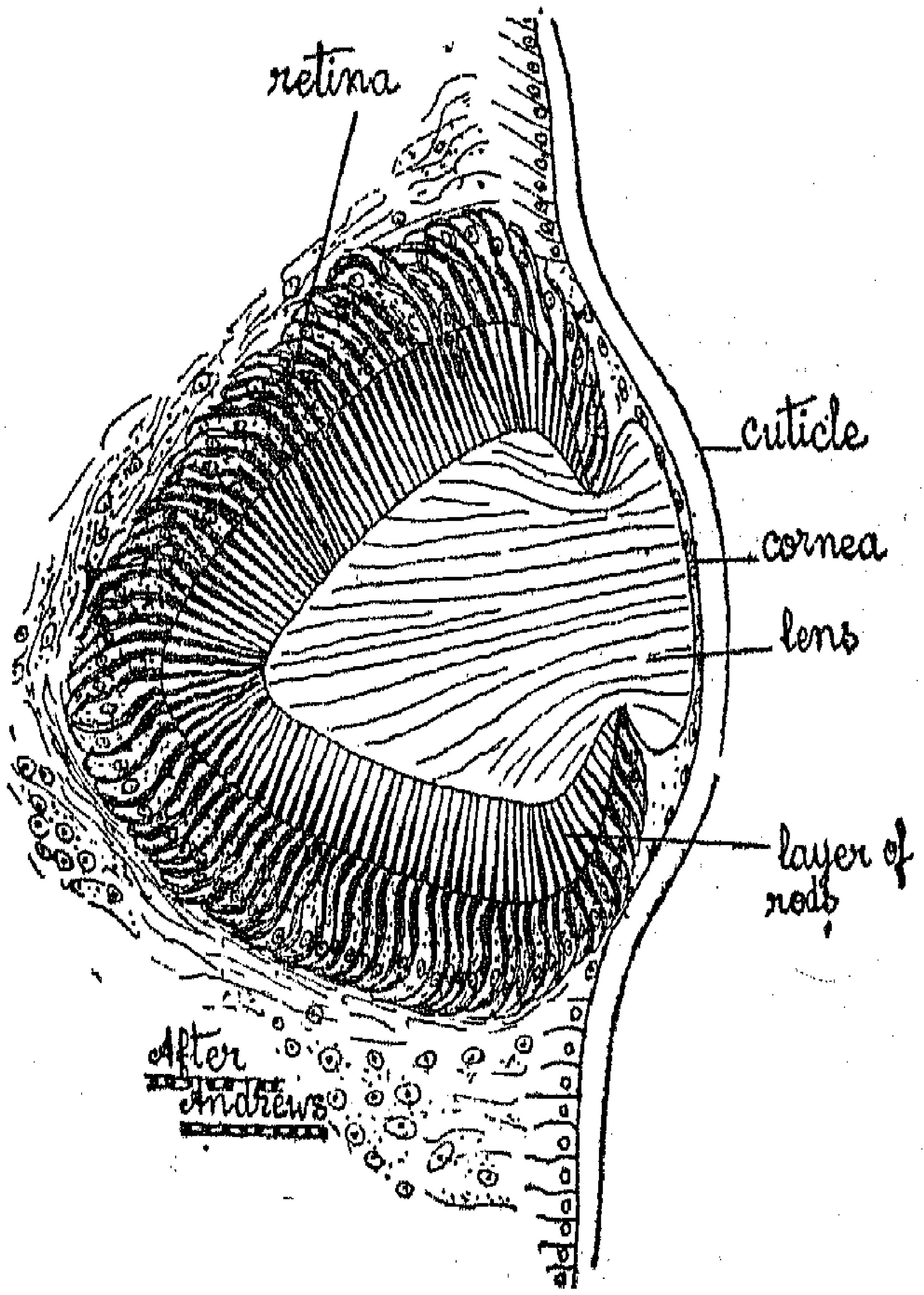


Fig. 190. Section through the eye of Nereis.

38

Pheretima, an Oligochaete Worm (The Common Earthworm)

1. **Describe the structure of the septal nephridium of Pheretima. What are the peculiarities of the nephridial system of this animal?** (Agra, 1957)

2. **Give an account of the septal nephridium of** *Pheretima*. **Why does it belong to the enteronephric type? What is the advantage of this type of nephridial system to the worm?** (P. C. S., 1956)

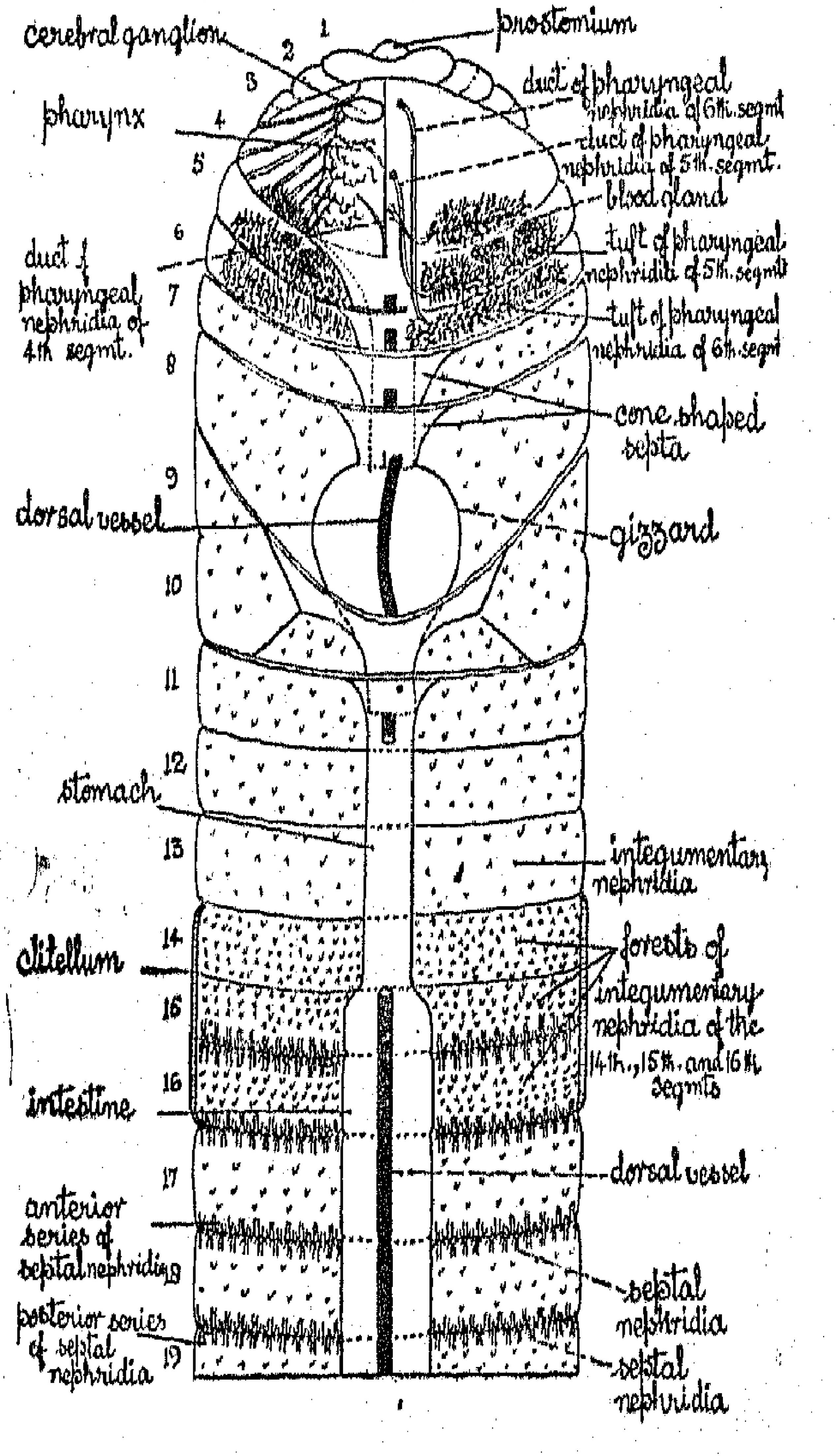

cerebral ganglion
prostomium
1
2
3
duct of pharyngeal nephridia of 6th. segmt
pharynx
4
duct of pharyngeal nephridia of 5th. segmt.
5
blood gland
6
tuft of pharyngeal nephridia of 5th. segmt
duct of pharyngeal nephridia of 4th segmt.
7
tuft of pharyngeal nephridia of 6th segmt
8
cone shaped septa
9
dorsal vessel
gizzard
10
11
12
stomach
13
integumentary nephridia
clitellum
14
forests of integumentary nephridia of the 14th., 15th. and 16th segmts
16
16
intestine
dorsal vessel
17
anterior series of septal nephridia
18
septal nephridia
posterior series of septal nephridia
19
septal nephridia

Fig. 191. General plan of nephridial the system of Pheretima (Diagrammatic representation after Bahl).

3. **Explain clearly the mechanism of feeding in** *Nereis* **and compare it with that of** *Pheretima.* (Agra, 1955)

4. **Give an account of the structure of the following :**

(a) **integument of** *Pheretima* (b) **Typhlosole of** *Pheretima.*

5. **Give an account of the reproductive system of** *Pheretima* **by means of diagrams only.**

The **excretory system** in *Pheretima* like all other earthworms consists of coiled tubular structures known as *nephridia* although the plan of the system presents certain remarkable features in case of Pheretima.

The most important feature of the excretory system of *Pheretima* is that the **greater part of the excretory fluid is poured into the gut through elaborate canals and ducts** and only a small part of the excretory fluid goes out through the openings of the nephridia (the *nephridiopores*). The excretory fluid is discharged into the lumen of the intestine in *Pheretima* and such a system is known as the **enteronephric nephridial system;** it has been suggested that the system is an adaptation for *conservation* of water which is reabsorbed by the intestinal wall.

There are **no nephridia in the first three segments.**

The nephridia of *Pheretima* are of three kinds :

(1) *The septal nephridia* : attached to each septum behind the 15th segment on its anterior as well as the posterior face.

(2) The *integumentary nephridia* : attached to the inner surface of the body wall in all segments except the first six.

(3) The *pharyngeal nephridia* : found only in the 4th., 5th. and 6th. segments in the form of tufts or bunches, each tuft consisting of a very large number of nephridia.

(1) A **septal nephridium** consists of (i) a *funnel* or *nephridiostome* (ii) a *neck* (iii) a *body* consisting of a short *straight lobe* and a *spirally twisted loop* and (iv) a *terminal nephridial duct.*

By means of the funnel, the nephridium communicates with the coelom ; the funnel has an elliptical opening the *mouth* which lies between a large *upper lip* and a small *lower lip* each formed by a number of ciliated cells. The funnel leads into a narrow ciliated tubule which forms a very long canal in the body of the nephridium ; the canal makes several loops in the body of the nephridium. The whole of the *septal nephridium* lies in one and the same segment i. e. the *nephridium is unisegmental.*

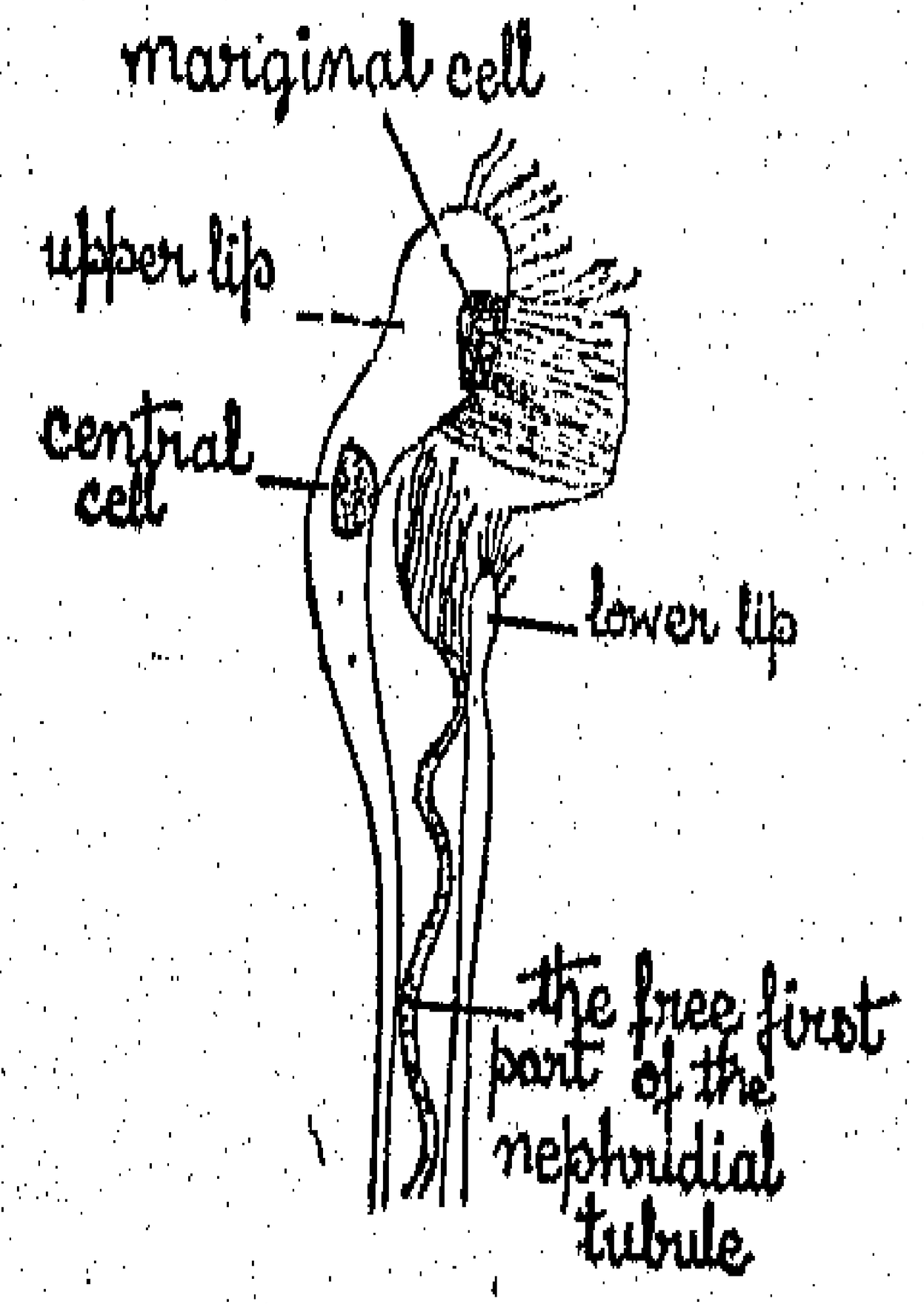
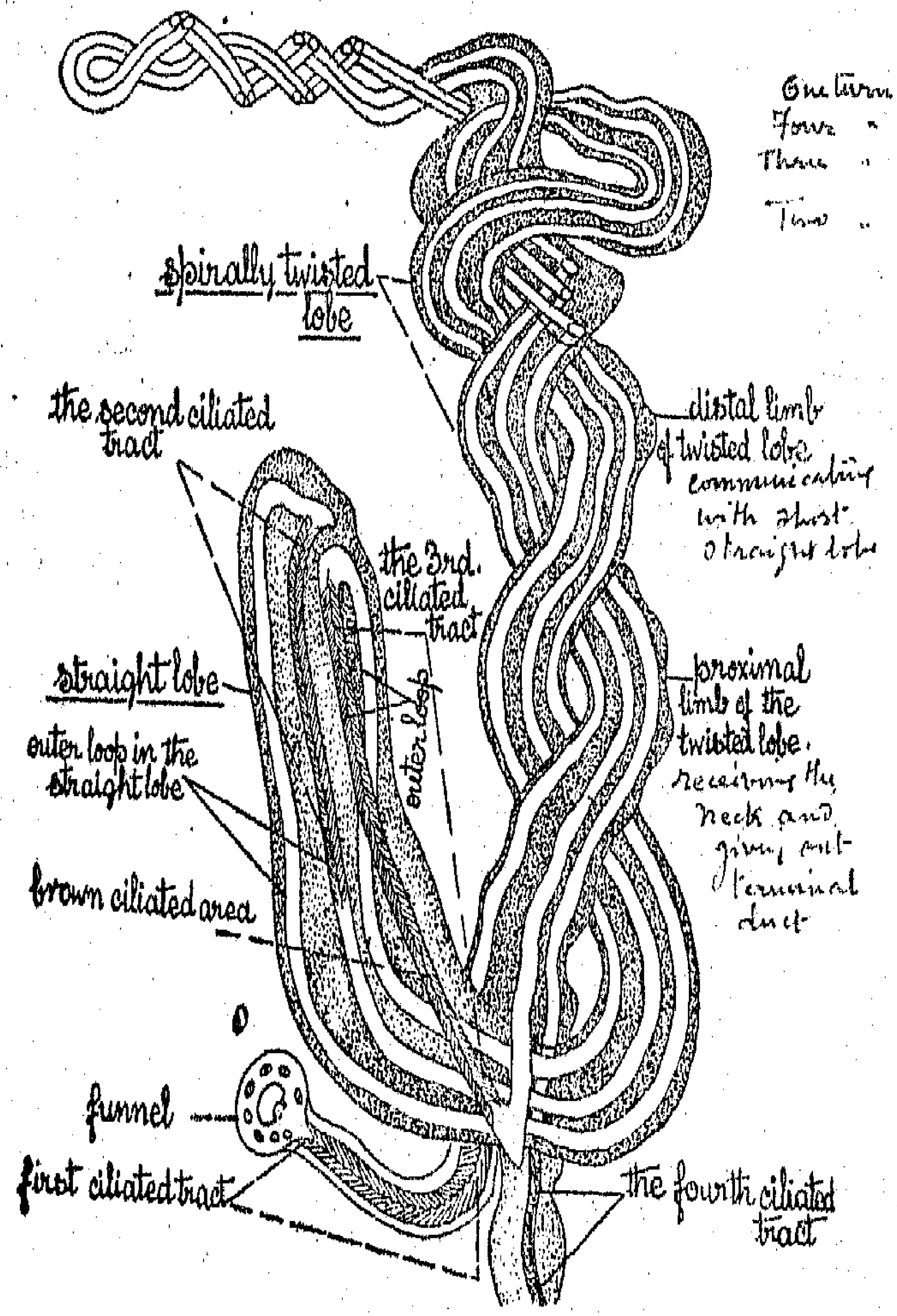


Fig. 192. A longitudinal section of the funnel of the septal nephridum (After Bahl).

These nephridia are arranged in rows on the front as well as the back of the intersegmental septa behind the 15th. segment ; two such rows of nephridia are found on the front face of the septa, one on the right and the other on the left of the gut and two similar rows are found on the posterior face of each septum. About 50 nephridia are found on the anterior face and about an equal number on the posterior face of each septum. The total number of septal nephridia in each coelomic compartment varies between 80 and 100.


spirally twisted lobe
the second ciliated tract
the 3rd. ciliated tract
straight lobe
outer loop in the straight lobe
outer loop
brown ciliated area
funnel
first ciliated tract
distal limb of twisted lobe communicating with short straight lobe
proximal limb of the twisted lobe. receiving the neck and giving out terminal duct
the fourth ciliated tract

One turn in neck
Four " " st. lobe
Three " " basal part } of
Two " " apical part } twisted loop
[illegible] as well as distal

Fig. 193. A septal nephridium of Pheretima showing the course of the nephridial canal and the ciliated tracts (After Bahl) Read twisted loop in the labels above for twisted lobe.

In the body of the nephridium, the straight lobe is less than half the length of the spirally twisted loop ; the twisted loop consists of a *proximal limb* and a *distal limb* both of which are spirally twisted around each other. The short *straight lobe* is continued into the distal limb of the spirally twisted loop at the base of the body ; the ciliated tubule from the funnel continues into the proximal limb ; the *proximal limb* also gives off the *terminal duct,* In the *straight lobe*, four canals run nearly parallel to one another; in the basal part of each of the two limbs of the twisted loop, three parallel canals are found while in the apical part, there are only two parallel canals. The *cilia* which are arranged on the nephridial funnel along several rows radiating from its mouth to its periphery, beat simultaneously towards the mouth.

There are four *ciliated tracts* in the body of the nephridium, which occur along the course of the nephridial canal; the *first ciliated tract* lies in the narrow neck following the funnel while the *fourth one* is found in the terminal duct of the nephridium. The *second* and the *third* ciliated tracts lie in the straight lobe. The cells surrounding the third ciliated tract accumulate certain *dark brown granules* stated to be excretory in nature.

Running parallel and internal to the commissural vessel on each side is found a *septal excretory canal.* The *terminal ducts* of all the septal nephridia open into the septal excretory canal of the corresponding side, the right or the left, as the case may be. The nephridia thus deliver their excretory fluid to the septal excretory canal. Just beneath the dorsal vessel and above the intestine is found a pair of *supra-intestinal excretory ducts* which extend longitudinally in the mid-dorsal region from behind the 15th segment up to the posterior body end. The two supra-intestinal excretory ducts lie side by side. The pair of septal excretory canals on each septum opens into the pair of supra-intestinal excretory ducts. Thus the excretory fluid from all the septal nephridia of all the segments, coming first into the septal excretory canals, is finally collected into the supra-intestinal excretory ducts. One or the other supra-intestinal excretory duct opens by a minute ductule into the lumen of the intestine at the level of each septum.

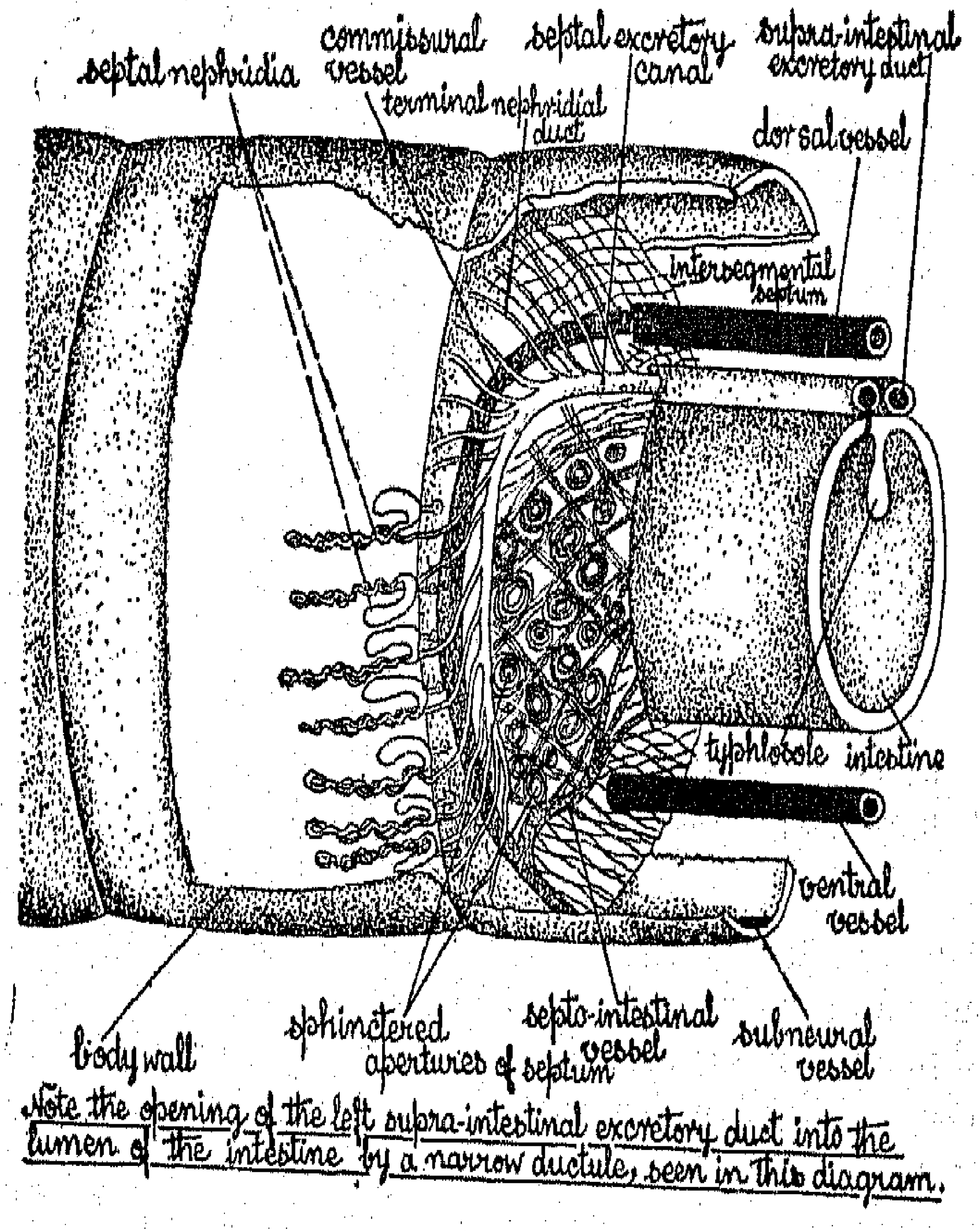

septal nephridia
commissural vessel
terminal nephridial duct
septal excretory canal
supra-intestinal excretory duct
dorsal vessel
intersegmental septum
typhlosole
intestine
ventral vessel
body wall
sphinctered apertures of septum
septo-intestinal vessel
subneural vessel
Note the opening of the left supra-intestinal excretory duct into the lumen of the intestine by a narrow ductule, seen in this diagram.

Fig. 194. The enteronephric nephridial system in Pheretima
(A diagrammatic representation after Bahl.)

The excretory fluid from the supra-intestinal excretory ducts passes through these minute ductules into the lumen of the intestine; waste products from the coelomic fluid and blood→septal nephridia→septal excretory canals→supra-intestinal excretory ducts→minute narrow ductules at the level of each intersegmental septum→lumen of intestine→anus→exterior. In this segmental enteronephric nephridial system, the waste products (ammonia, urea and creatinine) are discharged first into the intestinal lumen and then out to the exterior through the anus.

2. The **integumentary nephridia** are smaller in size than the septal and the pharyngeal nephridia and can hardly be detected without the aid of a hand lens. The integumentary nephridia lie scattered on the parietal surface of the body wall in all segments except the first six. Each segment contains about 250 integumentary nephridia but the 14th., 15th. and 16th. segments have them in an enormous number: each of these segments has about 2000 to 2500 such nephridia. *The integumentary nephridia lack a funnel and neck, the straight lobe is short and has only two ciliated tracts*; a twisted loop is present. These nephridia are thus closed internally, but each one of these opens to the exterior on the outer surface of the body wall by a minute *nephridiopore.* The integumentary nephridia open to the exterior and are hence described as *exonephric.*

3. The **pharyngeal nephridia** occur only in the 4th., 5th. and 6th. segments on either side of the pharynx and oesophagus in paired tufts, each tuft consisting of numerous nephridia. These nephridia are about as large in size as the septal nephridia but differ from them in the *absence of a coelomic funnel.* The terminal ductules of these nephridia join to form *ducts*, a number of which unite so that a pair of long thick-walled ducts is formed in each of the three segments. Such ducts from the nephridial tufts of the 4th and 5th. segments open into the pharynx while the pair of ducts from the nephridial tufts of the 6th segment opens into the buccal cavity. (See figure no. 191) The pharyngeal nephridia are also a part of the *enteronephric system* because they also discharge their excretory fluid into the lumen of the gut.

The excretory system in *Pheretima* thus consists of (i) an *enteronephric system* consisting of the septal nephridia and the pharyngeal nephridia and (ii) an *exonephric system* consisting of the integumentary nephridia. In the enteronephric system, the excretory waste is discharged into the lumen of the intestine where the water is reabsorbed by the intestinal walls; **the system in**

this manner serves to conserve water. In the exonephric system, the excretory fluid is discharged to the exterior directly.

The nephridial tubules are richly supplied with blood capillaries and are also at places lined with gland cells and cilia which work towards the exterior. Water along with nitrogenous waste products passes by diffusion into the blood whence it passes on to the nephridia whose gland cells extract the waste products which then come into the cavities of the nephridial tubule, the nephridial canals→terminal ducts→septal excretory canals→supra-intestinal excretory duct→narrow small ductules near each septum (in case of septal nephridia) ; terminal ducts→long thick ducts→buccal cavity and pharynx (Pharyngeal nephridia) ; and to the exterior directly through the nephridiopores in case of integumentary nephridia. Excretory material in the coelomic fluid also passes through the funnels of the septal nephridia into the nephridial tubules. Thus the waste products are excreted by the nephridia both from the *coelomic fluid* and *blood*. The nephridia have an important role in the maintenance of osmotic balance of the earth worm. Water and salts enter Pheretima's body through the body-wall creating an excess of water in the body ; a hypotonic urine is actively secreted and eliminated by the nephridia.

Feeding in Nereis and Pheretima Compared

Nereis (Feeding)	*Pheretima* (Feeding)
1. It is *carnivorous*, feeds upon small crustaceans, molluscs and other small animals which it seizes by means of the 'jaws and teeth' lying in the wall of the stomodaeum. The cuticular lining of the buccal cavity and the pharynx presents localised thickenings which in the region of the buccal cavity take the form of very small irregularly arranged chitinous *denticles*. Near the posterior end of the pharynx one pair of these cuticular thickenings is large and forms the 'jaws' ; these 'jaws' are laterally placed and their movements are controlled by muscular bundles in the thick walls of the pharynx in its posterior region. The inner	1. Swallows large quantities of earth from which it extracts nutritive organic material. The earthworms usually swallow soil rich in organic particles (humus). They also feed on leaves and other vegetable matter. The leaves are held against the mouth due to the sucking action of the pharynx; before swallowing the leaves are moistened with juices containing enzymes secreted by pharynx. The ingested earth may also contain minute animals. *Denticles and 'jaws' are not found.*

39

Hirudinaria the Leech A Comparative Study

1. **Give an account of the haemocoelomic system of Hirudinaria.** (L.U.B.Sc., Pass, 1953, 1957)
2. **Compare the modes of locomotion in Earthworm, Nereis and Leech.** (L.U.B.Sc., Pass, 1960)
3. **Compare the alimentary canal of earthworm, *Nereis* and leech.** (L.U.B.Sc,. Pass 1959, 1960)
4. **Give a comparative account of the nephridial system in Nereis, Pheretima and Hirudinaria** (L.U.B.Sc., Pass, 1954)
5. **Describe the reproductive organs of Hirudinaria.** (L.U.B.Sc., Pass, 1958)
6. **Describe the excretory organs of Pheretima and Hirudinaria.** (L.U.B.Sc., Pass, 1955)

The leech *Hirudinaria* (Phylum *Annelida*, class *Hirudinea*, order *Gnathobdellida*) is very common in fresh water tanks, ponds and still waters. It sucks blood of its victims which include cattle that go in or near water and the barefooted men and women working in the fields. In a single meal it ingests a large quantity of blood which nourishes it for several months.

The anterior end presents a ventrally facing anterior sucker formed by the fusion of a few anterior segments with the prostomium. At the posterior end is a large muscular posterior sucker composed of seven segments (27th. to 33rd.) The total number of segment in the body is 33, a typical segment has five annuli.

Locomotion in the leech is of two kinds: (i) *crawling* on a substratum submerged in water or on land *after the manner of a looping caterpillar* and (ii) *swimming*.

(i) In crawling, first of all the posterior sucker is fixed on the substratum ; this induces the circular muscles of the body to contract, the longitudinal muscles relax simultaneously. As the posterior sucker is fixed and the circular muscles of the body contract, the body elongates to its maximum and then the anterior end is fixed on the substratum ; the fixation of the anterior sucker initiates a wave of excitation and contraction over the longitudinal muscles and simultaneous relaxation of the circular muscles. As the anterior sucker is fixed and the longitudinal muscles contract, the posterior sucker leaves the substratum and is drawn forward near the anterior sucker; the body of the leech is also drawn forward as the posterior sucker moves forward. The posterior sucker

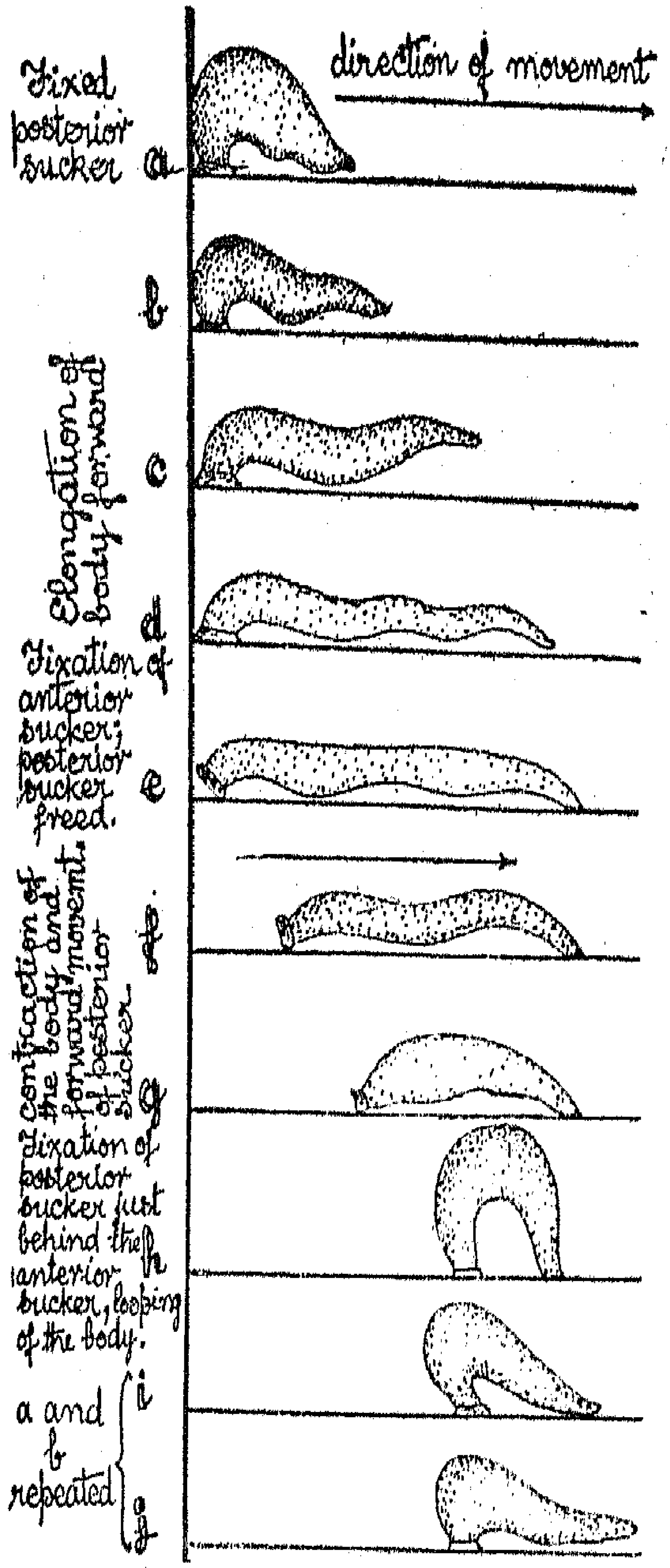

direction of movement
Fixed posterior sucker
a
b
c
Elongation of body forward
d
Fixation of anterior sucker; posterior sucker freed.
e
f
contraction of the body and forward movement of posterior sucker
g
Fixation of posterior sucker just behind the anterior sucker, looping of the body.
h
i
a and b repeated
j

Fig. 202. A series of diagrams showing movement of a leech on a substratum (After Bhatia).

then gets fixed up near the anterior sucker, the body forms a loop. As the posterior sucker becomes fixed again, a wave of excitation and contraction over the circular muscles of the body is initiated and the whole sequence of rythmic muscular activity is repeated again. The dorso-ventral muscles remain unconcerned during the crawling.

(ii) In *swimming*, successive undulatory movements of the body are performed and the locomotion is brought about by the propagation of bilateral waves of contraction along the relaxed longitudinal muscles, the dorsoventral muscles remaining in a state of tonic contraction. The leech becomes dorsoventrally compressed assuming the appearance of a flattened band which exhibits eel like swimming movements. The leech swims when prevented from getting attached by suckers to solid substratum.

It is clear now that the main elements taking active part in locomotion are the *circular*, *longitudinal* and the *dorsoventral* muscles which are continued into the suckers also. It may also be noted that the suckers adhere to the substratum due to the slimy secretion of the sucker glands and *not* by creating a vacuum.

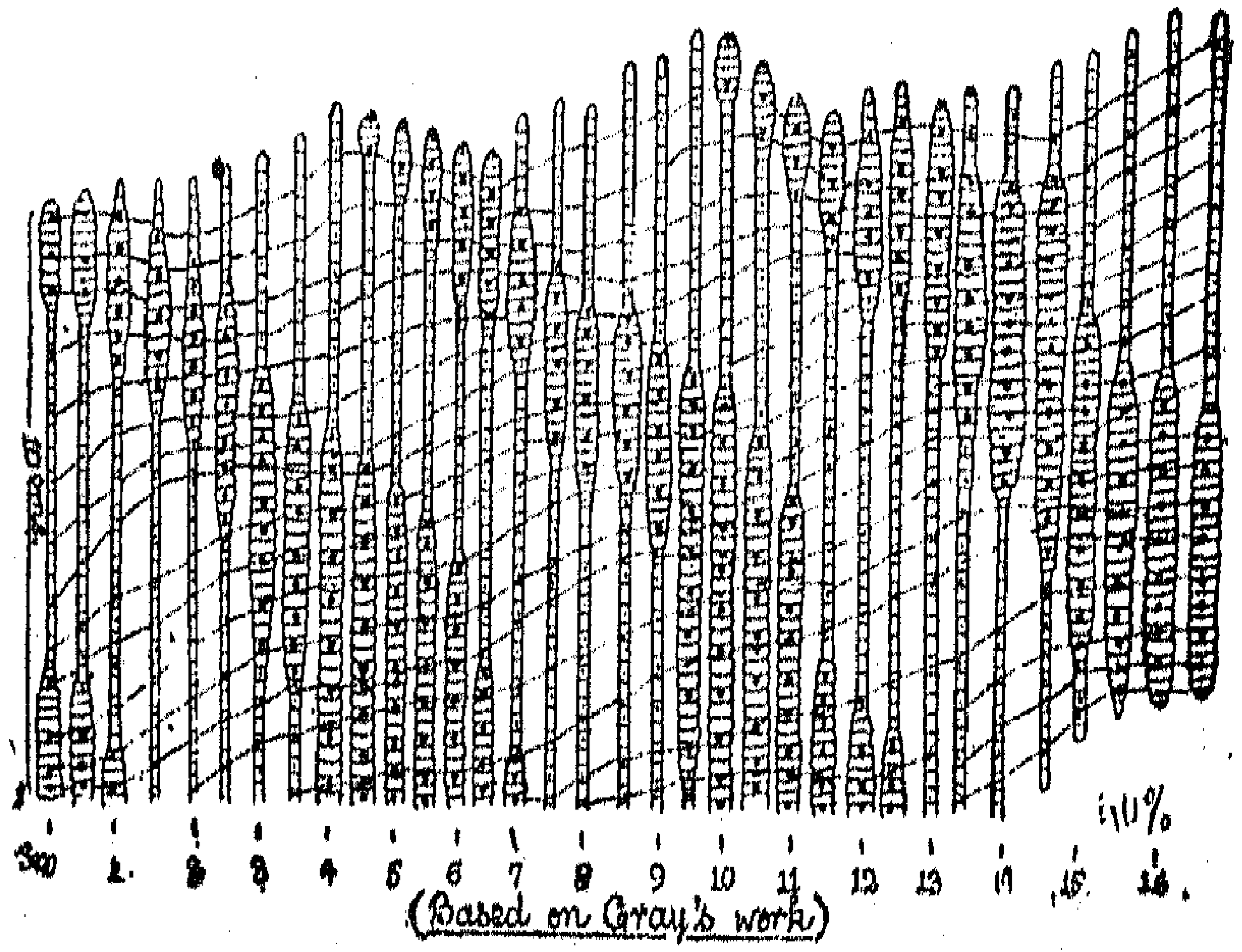


Fig. 203. Diagram (from a cinematograph record) showing the mode of locomotion of an earthworm (After (ray).

Locomotion in earthworm, Nereis and leech compared:

Earthworm	*Nereis*	*Leech*
1. [Lives in burrows in the ground, *crawls on surface.*]	1. [Inhabits the burrows in the sand or mud of the sea-shore between tidemarks; *usually creeps on the bottom* of sea but *also swims.*]	1. [Lives in fresh water tanks, ponds etc. It *crowls on a substratum by looping movements* and also *swims.*]
2. The locomotion is brought about	2. Locomotion is brought about by the	2. The main elements taking part in loco-

Earthworm	*Nereis*	*Leech*
by the *circular* and *longitudinal muscles*, the *septa* and the *setae*. Parapodia are absent. A sucker-like action is performed by mouth to secure grip of surface (aided by sticky mucus) in locomotion on smooth surface. No true suckers are found.	*parapodia*, a pair of laterally placed movable muscular processes on each segment. The *parapodia* bear bundles of setae and are equipped with elaborate musculature. No suckers are found.	motion are the *circular*, *longitudinal* and the *dorsoventral muscles* which are continued into the *suckers* also. Setae and parapodia are absent.
3. (i) First of all the circular muscles in the anterior region contract so that this region becomes elongated and narrowed; the wave of contraction then passes over to the backward region of the body. (ii) The circular muscles at the anterior end of the worm then relax, shortening and thickening the anterior region because the longitudinal muscles contract at the same time. The wave of contraction of the longitudinal muscles passes backward and soon vanishes to be replaced by the [3] next wave of contraction of the circular muscles starting from the anterior end, the longitudinal muscles are now relaxed, as a result of which the anterior region again becomes elongated and moves forward. The forward progression continues during the phase of the contraction of the circular muscles and the simultaneous relaxation of the longitudinal muscles. (4) The circular muscles again relax and the longitudinal muscles contract so that the segments of the anterior region gradually come to rest. The worm moves forward by alternate waves of contraction in the circular and longitudinal muscles of the segment.	3. The *parapodial muscles are modified circular muscles* of the body wall. The parapodium has *protractor muscles* the contraction of which brings about protrusion of the parapodium; there are also the *retractor muscles* which on contraction cause retraction of the parapodium. The complex muscular equipment of the parapodia assists in their varied movements performed during the swimming and creeping movements of the worm. The parapodia aid in creeping and function as a *series of oars* for propelling it through the water. In *Heteronereis*, the parapodia become leaf-like and oar shaped setae become developed. The Heteronereis swims actively in water by the wriggling body movements assisted by paddling movements of the foliaceous parapodia with their long oar-like setae.	3. *Circular* and *longitudinal* muscles show rythmic activity while the dorsoventral muscles remain unconcerned; this way, the leech performs crawling movements after the manner of a looping caterpillar. The suckers also take part as already described above. In swimming movements, the body performs undulatory movements and bilateral waves of contraction are propagated along the relaxed longitudinal muscles; the dorsoventral muscles remain in a state of tonic contraction. The leech swims only when prevented from attaching by suckers to solid substratum so that no tactile exteroceptive stimulation is possible.
4. The normal mode of locomotion is creeping. Swimming does not occur.	4. *Nereis* normally crawls on the substratum; can swim. *Heteronereis* is pelagic and swims actively.	4. Normally the leech *crawls* on a substratum submerged in water or on land *after the manner of a looping caterpillar*. Swims only when prevented from attaching by suckers.

Digestive system

The **alimentary canal** in *Hirudinaria* is straight. To start with, there is a *pre-oral chamber*: a cup-shaped depression on the ventral surface of the anterior sucker, at the centre of which is found the triradiate *mouth* opening. The prostomium and the first four segments form the roof of the pre-oral chamber. A *velum* with three lips guards the mouth opening and forms a complete partition between the pre-oral chamber and the *buccal cavity*, the *latter* being a short chamber lying immediately behind the velum. One medio-dorsal and two ventro-lateral *crescentic jaws* are found imbedded in the mucous membrane of the buccal cavity just behind the radiating lines of the mouth. Each jaw is a muscular cushion with a cuticular covering bearing a dentigerous ridge along its summit. A number of openings of the salivary glands are found on small salivary papillae found on each side of a jaw.

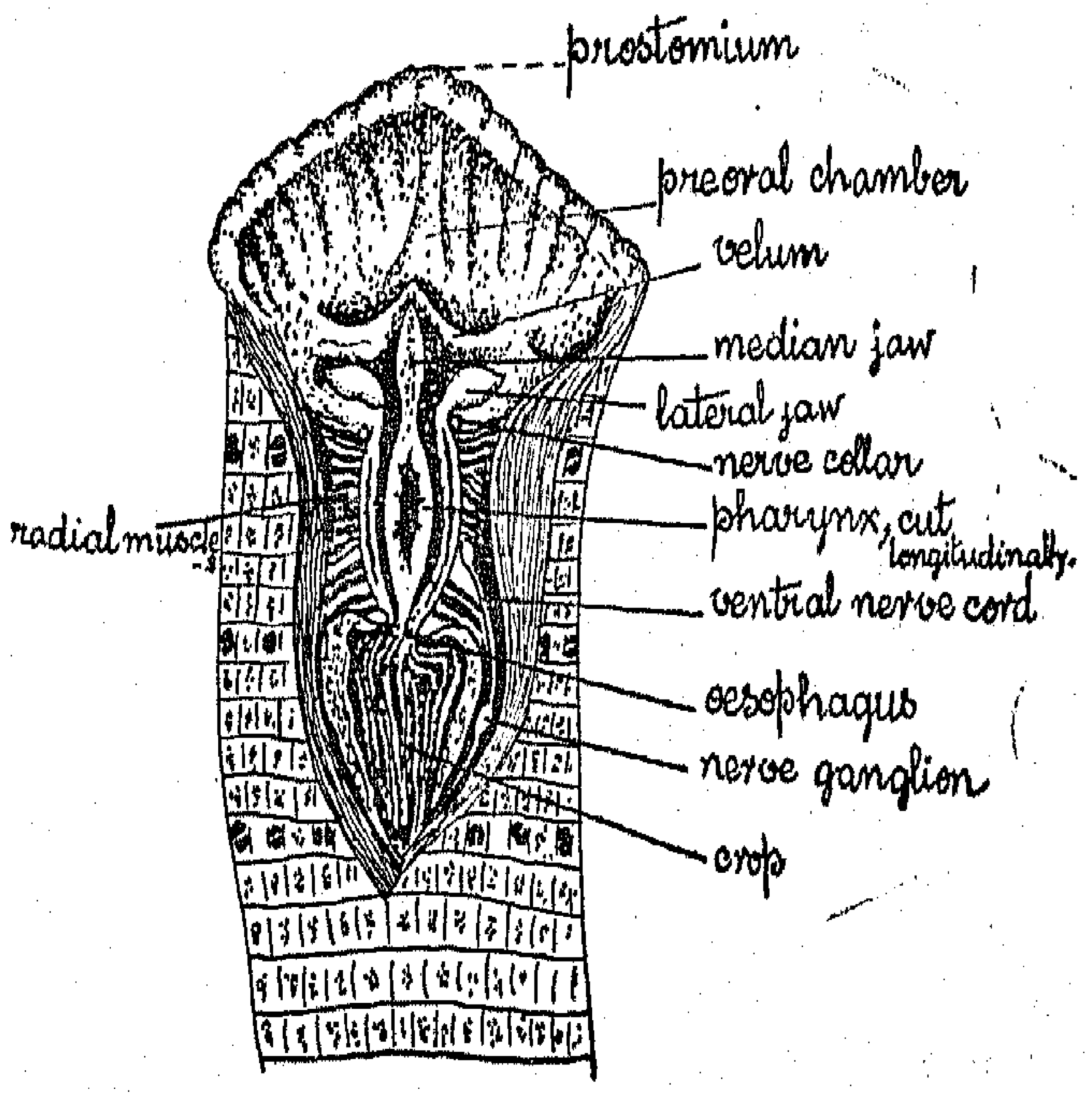


Fig. 204. The anterior region of the leech dissected out from the ventral side. (Diagrammatic).

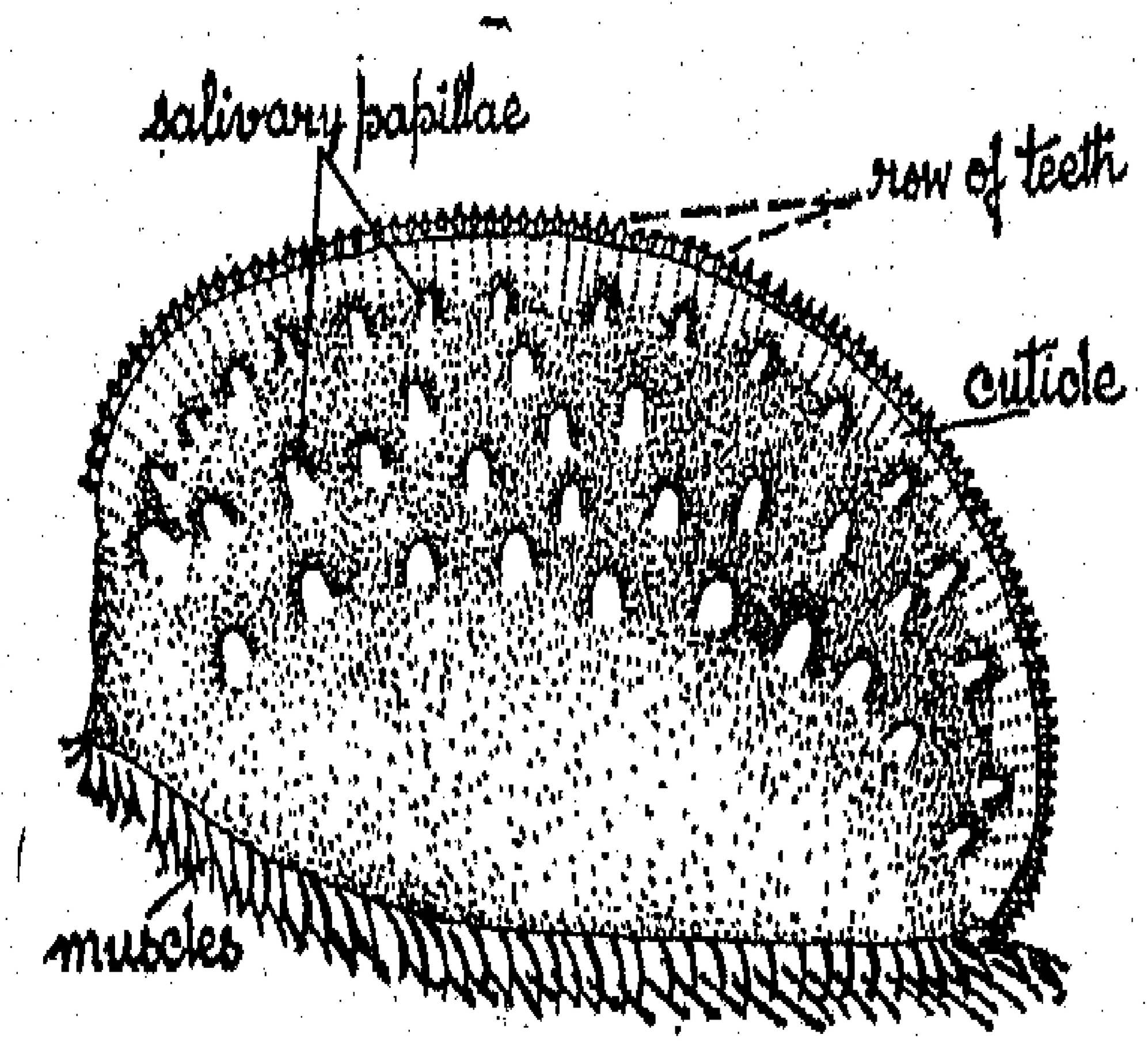


Fig. 205. Side view of a jaw. (After Bhatia).

The parts of the alimentary canal are: a short *buccal cavity*, an oval sac-like muscular *pharynx* (carrying on its outer wall large aggregations of unicellular salivary glands which secrete *anticoagulin* for preventing the coagulation of blood), a ten-chambered *crop*, a small heart shaped *stomach* (whose walls are internally produced into anastomosing folds), a narrow tubular *intestine* (whose internal wall is beset with transverse and longitudinal folds which increase its absorptive surface) and a thin-walled *rectum* which opens through the anus to the exterior. The anal opening lies on the dorsal surface at the root of the posterior sucker i. e. at the end of the 26th segmt.

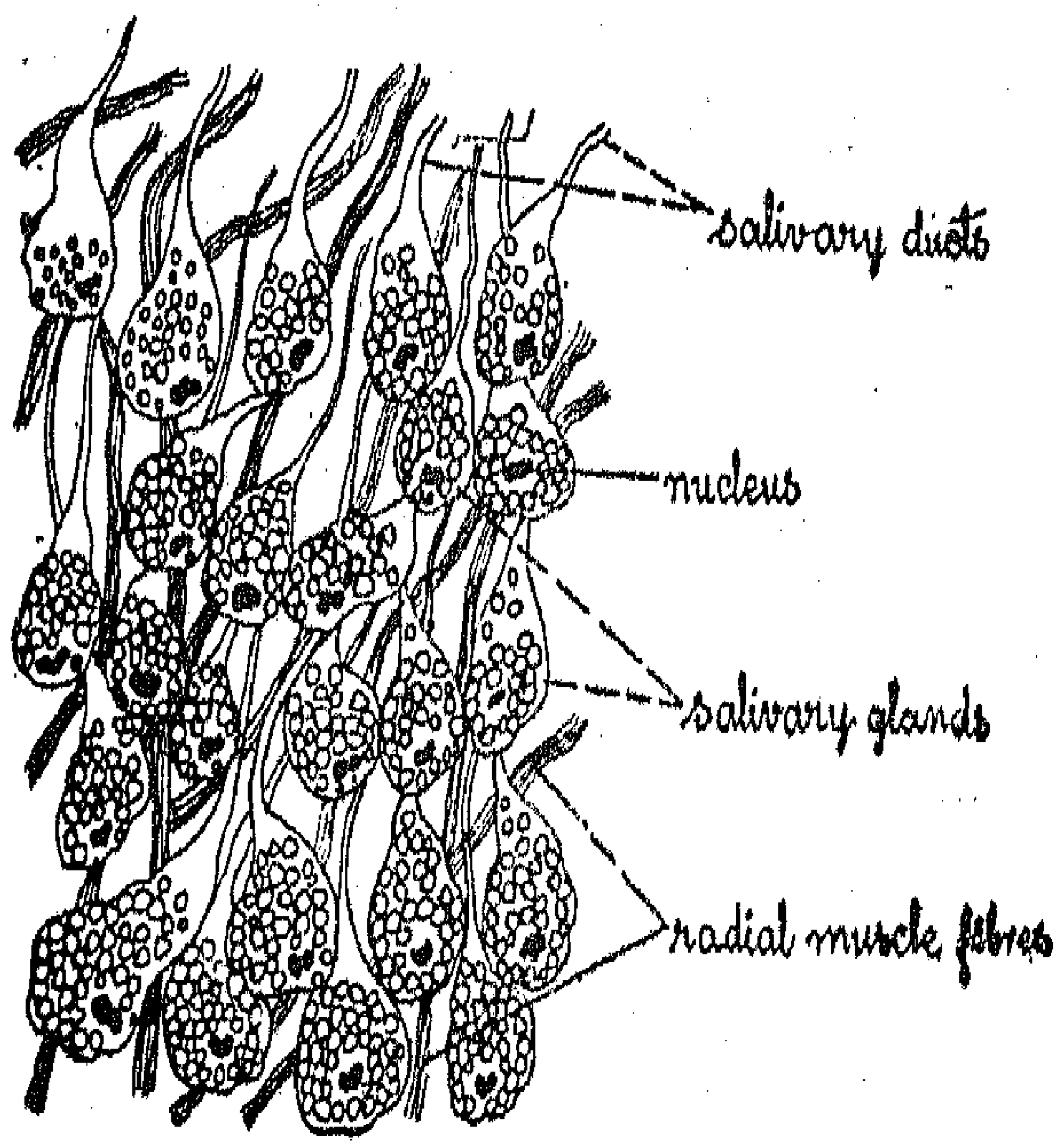


Fig. 206. The salivary glands of Hirudinaria.

The most remarkable part of the alimentary canal is the *crop* (9th to 18th segmts.) which is made of ten thin-walled chambers situated one behind the other and communicating by sphinctered openings; the broad posterior part of each chamber is produced into backwardly directed caeca which become expanded with blood after a good meal; the tenth chamber of the crop is larger than all others and its caeca extend up to the 22nd segment.

The pre-oral chamber is lined with a thin *cuticle* continuous with that of the body wall; beneath the cuticle is the *epidermis* which is also continuous with that of the body wall. In the buccal chamber, along the summit of each jaw, the internal cuticle forms teeth which occur in a single row. The *pharynx* possesses a similar *cuticle* and beneath it, the *ephithelial lining*. The pharynx is highly muscular and helps the leech in efficiently sucking the blood of the prey during the feeding. The pre-oral *chamber*, the *buccal cavity* and the *pharynx* which are all internally lined with cuticle represent the *fore-gut*. No such cuticular lining is found in oesophagus, crop, stomach and intestine which constitute the *mid-gut*; the rectum lined with cuticle represents the *hindgut.*

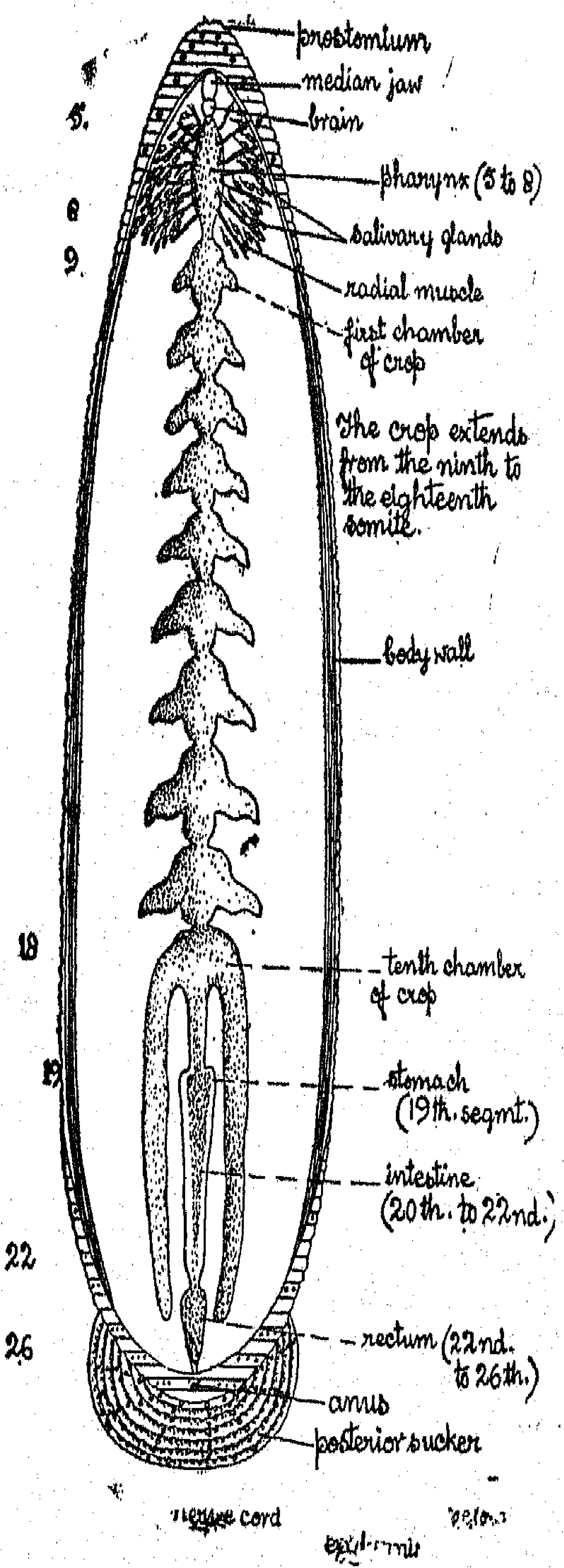


Fig. 207. Diagram showing the alimentary canal of leech.

Mode of feeding : The leech lives upon the blood of cattle that go in or near water and the barefooted men and women working in the fields. The leech secures a firm hold upon the prey by its powerful posterior sucker and then the anterior sucker is brought into action. The pre-oral chamber is flattened, the three lips of the velum contract to permit the jaws to protrude out through the triradiate mouth into the pre-oral chamber and the inner surface of the pre-oral chamber becomes tightly applied to the body of the victim. The serrated edges of the jaws work against the skin of the prey with pressure and force and pierce the skin to a sufficient depth making a triradiate incision; the blood vessels of the integument of the victim are punctured and the leech sucks in a large quantity of blood by means of the sucking action of the muscular pharynx aided by the *buccal cavity* and the *pre-oral chamber.* The leech may suck in one meal, several times its own weight of blood. The digestion and absorption of a single such meal may take about 10 to 14 months.

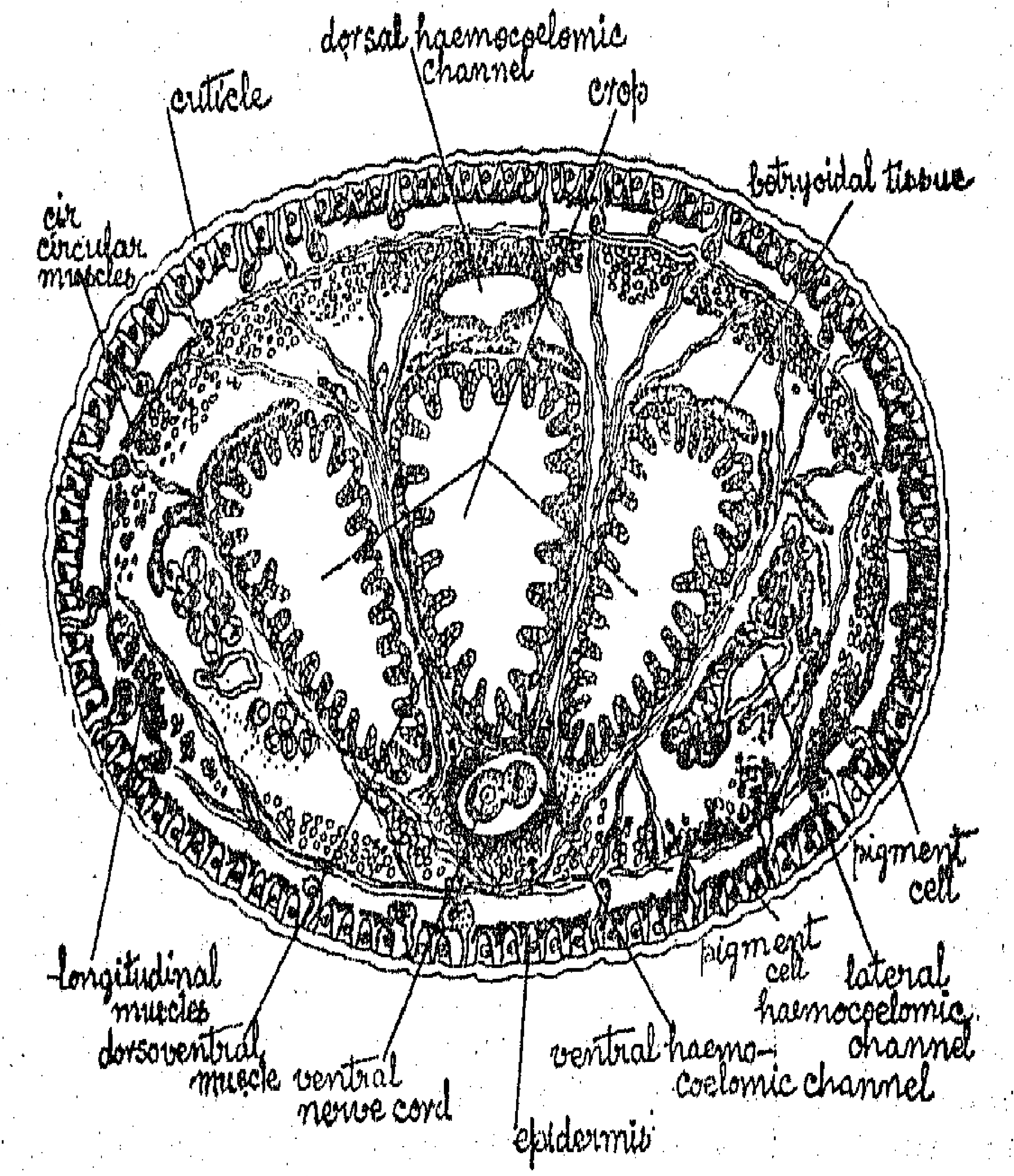


Fig. 208. Transverse section of Hirudinaria passing through the region of the crop and its two diverticulla. (After Bhatia).

The saliva of the leech contains *anticoagulin* due to which the blood does not coagulate. The blood is stored up in the various chambers of the crop and its diverticula and as a result, the leech becomes distended. Inside the crop, the blood-corpuscles burst and their haemoglobin goes into solution i. e. the blood is haemolysed. Digestion and absorption occur in the stomach and intestine. A peptolytic ferment is found which splits up tyrosin and hydrolyses proteins in an alkaline medium. The elongated villi of the intestine enhance its absorptive surface; the folds and villi of the intestine are richly supplied with haemocoelomic capillaries. The undigested remains are passed out through the anal opening.

Alimentary canal of the earthworm, Nereis and the leech compared

Earthworm	Nereis	Leech
1. The alimentary canal does not coil but extends straight from mouth to anus which are at the anterior and posterior body ends respectively. The alimentary canal is not uniform in diameter or in the nature of its walls.	1. The alimentary canal does not coil but extends straight from mouth to anus which are at the anterior and posterior body ends respectively. The alimentary canal is not uniform in diameter or in the nature of its walls.	1. The alimentary canal does not coil but extends straight from mouth to anus; the mouth lies at the anterior end while the anus lies at the root of the posterior sucker on the dorsal surface. The alimentary canal is not uniform in diameter or in the nature of its walls.
2. The alimentary canal consists of (i) *buccal cavity* (ii) *pharynx* (iii) *oesophagus* (iv) *gizzard* (v) *stomach* (vi) *intestine* and (vii) *rectum.*	2. The alimentary canal consists of (i) *buccal cavity* (ii) *pharynx* (iii) *oesophagus* (iv) *intestine* (v) *rectum.*	2. The alimentary canal consists of (i) *pre-oral chamber* (ii) *buccal cavity* (iii) *pharynx* (iv) *oesophagus* (v) *crop* with ten chambers (vi) *stomach* (vii) *intestine* and (viii) *rectum.*
3. The *buccal cavity* can be protruded or retracted for picking up the food particles along with earth. The pharynx is not eversible. No 'jaws' like those of *Nereis* and leech are found anywhere in the alimentary canal; the jaws are not needed because the worm feeds on minute organic particles mixed with earth. Even the denticles are not found anywhere.	3. The buccal cavity as well as the pharynx are everted out forming a *proboscis*; this is done for the capture of prey. The cuticular lining of the buccal cavity bears small chitinous *denticles* and there are in addition, near the posterior end of pharynx a pair of laterally located movable *jaws* See fig. 180), with a serrated inner edge. The jaws and the 'teeth' are used to capture small animals used as food by the carnivorous rag worm.	3. The 'jaws' imbedded in the mucous membrane of the buccal cavity protrude out during the bite of the leech prior to the suction of blood. The pharynx is not everted out. Three crescentic 'jaws' are found which bear a dentigerous ride along their summit. The jaws with their serrated edges are used to make an incision on the victim.
4. On the roof of the pharyngeal cavity is a richly vascular dorsal *pharyngeal mass* which has pharyngeal gland cells, musculo-vascular tissue and a ciliated pharyngeal epithelium. The pharyngeal gland cells secrete saliva. The pharyngeal mass functions like a true salivary gland and secretes mucus and a proteolytic enzyme. The lateral walls of the pharynx are pushed inwards horizontally into a sort of shelf on each side, the two 'lateral inpushings' appear to divide the pharynx into a 'dorsal salivary' and a ventral conducting chamber.	4. No pharyngeal mass is found. There are no salivary glands; instead there are a pair of laterally placed oesophageal glands which secrete digestive enzymes and which open into the oesophagus. No pharyngeal shelves are found and the pharyngeal chamber is undivided.	4. Pharyngeal mass is not found. Pharynx has highly muscular walls adapted for the function of sucking. Large aggregations of unicellular pear shaped salivary glands cover the outer wall of the pharynx. Each salivary gland leads into a long ductule, opening on a salivary papilla on the side of jaws. The saliva contains *anticoagulin.* No pharyngeal shelves are found and the pharyngeal chamber is undivided.
5. The last part of oesophagus in the eighth segment is modified into a muscular *gizzard* which has a thick walls of circular muscle fibres and an internal lining of columnar epithelium covered with an internal	5. No gizzard is found. The cuticular lining of the *buccal cavity* and *pharynx* bears *denticles*; food is masticated in the *proctodaeum.*	5. No gizzard is found; nor any kind of mastication is required as the leech feeds on blood, a fluid food.

Earthworm	Nereis	Leech
cuticle. In the gizzard, food material is ground up against the internal cuticle and is finely divided.		
6. No crop is found. There is no special chamber for storage of the food ingested.	6. No crop is found. There is no special chamber for storage of the food ingested.	6. A ten-chambered *crop* is found in which large amount of blood-food is stored. The *crop* is thin-walled, expansible and the largest part of the gut.
7. The intestine is thin walled and has a weakly developed *typholosole* (from the 26th segmt. backward leaving the last 23 to 26 segments).	7. No typhlosole is found.	7. No typhlosole is found. The intestine is thin walled.
8. The successive layers in the gut wall starting from the outermost side inwards are (i) the peritoneal epithelium (ii) longitudinal muscle layer (iii) circular muscle layer and (iv) the epithelial lining of the alimentary canal. The epithelial lining of stomach and intestine is thrown into folds.	8. The wall of the gut consists of (i) visceral layer of coelomic epithelium (ii) a layer of longitudinal muscle fibres (iii) a layer of circular muscle fibres and (iv) a layer of epithelium which lines the lumen of the gut.	8. The pharyngeal wall has from the inner to the outer side: (i) *epithelial lining* (ii) *longitudinal muscle layer* (iii) *circular muscle layer* (iv) *radial muscles* which run in bundles: one end of each muscle is inserted on the pharyngeal epithelium while the other runs through the wall of the pharynx and is inserted on the body-wall. The epithelial lining of the *oesophagus, stomach* and *intestine* are thrown into folds. In the intestine, these folds or *villi* are narrow, elongated and more numerous.

The coelom in Hirudinaria

Between the body-wall and the alimentary canal is found the pigmented *botryoidal tissue*[1]; due to this tissue the coelomic cavity has been largely obliterated. The coelom is however represented by (i) *four haemocoelomic channels*: two *laterals*, one *dorsal* and one *ventral*; these channels contain the coelomic fluid which is *red* due to the dissolved haemoglobin. The red coelomic fluid is known as the *haemocoelomic fluid* and the channels containing it are designated as the *haemocoelomic channels*, the four haemocoelomic channels are in direct communication with one another at the posterior end; and (ii) *certain other spaces* e. g. *spaces* enclosed within the testis sacs and the ovisacs, the *tubular space* around each vas deferens and numerous *other spaces* found in between the visceral organs; all these spaces contain a colourless coelomic fluid which lacks haemoglobin. The walls of the dorsal and ventral channels have a coelomic epithelium; the lateral channels develop muscular walls only at a later stage; the ventral channel encloses the ventral nerve cord; these facts confirm that these channels have a coelomic space within them.

The Haemocoelomic system

The haemocoelomic system comprises (I) the four *longitudinal channels* and (II) the *capillary system.*

I. The **four longitudinal** channels are: (i) a *dorsal channel* (ii) a *ventral channel* and (iii) two lateral channels.

The dorsal channel extends along the mid-dorsal line beneath the body wall from the anterior to the posterior side; it has non-muscular valves and lacks valves altogether. In the sixth segment (in the anterior region) the dorsal channel divides to form a system of capillary network in the cephalic segments. All along its course, the dorsal channel sends branches, the *dorso-intestinals* to the gut. From the ventral side of the dorsal channel in each segment arise two pairs of branches, the *dorsolaterals* each of which runs outwards and divides and breaks up to form a capillary network in the dorsal and dorsolateral regions of the body-wall. In the 22nd segment, the dorsal channel bifurcates and the two branches pass downwards and enter the posterior dilation of the ventral channel. In the dorsal vessel, the fluid flows from the posterior to the anterior side.

The *ventral channel* is thinwalled and lies beneath the alimentary canal, extends from the anterior to the posterior end of the body and is wider than the dorsal channel. There are no

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[1] [The botryoidal tissue consists of a network of minute branching canals formed of perforated cells, arranged end to end. The walls of the canals are loaded with a dark brown pigment and the intracellular lumen is filled with the haemocoelomic fluid in communication with that of the haemocoelomic system].

valves in the ventral vessel or in its branches, the fluid in the ventral vessel flows from the anterior to the posterior end. In each segment, the ventral channel gives off two pairs of branches; **one pair** soon after its emergence near the nerve ganglion divides into a *ventral branch* capillarising in the body wall and an *abdomino*-dorsal which proceeds vertically upwards between the lateral caeca of the crop and breaks up into a capillary network in the dorsolateral side of the integument; the **second pair,** the *nephridial branches* arise immediately behind each nerve ganglion in the segments which contain the testis sacs; the nephridial branches are therefore only *eleven pairs*, one pair in each of the segments 12th. to the 22nd. The nephridial branch supplies the nephridium and then forms a capillary network in the bodywall. Passing over the testis sac, the nephridial branch forms the *perinephrostomial ampullae* containing the 'ciliated organ' of the nephridium. The 'ciliated organ' which remains soaked in the haemocoelomic fluid, manufactures corpuscles of the coelomic fluid. The cilia of the funnels of the ciliated organ due to their vigorous movements cause circulation of fluid within the ampullae. From the perinephrostomial funnel some fluid goes into the botryoidal capillaries where the corpuscles acquire pigment and form the chloragogen cells.

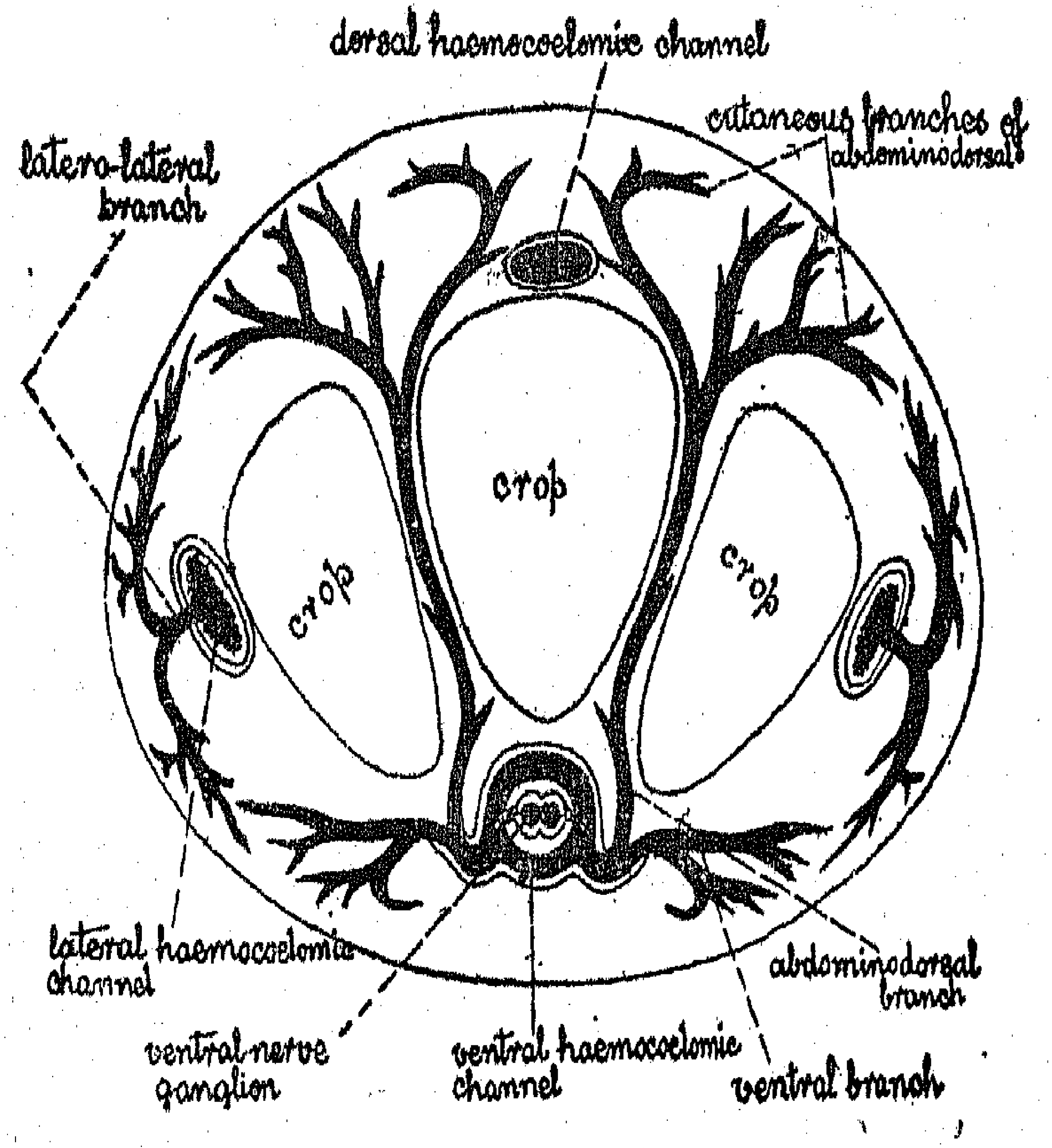
dorsal haemocoelomic channel
cutaneous branches of abdominodorsals
latero-lateral branch
crop
crop
crop
lateral haemocoelomic channel
abdominodorsal branch
ventral nerve ganglion
ventral haemocoelomic channel
ventral branch

Fig. 209. The haemocoelomic channels seen in a transverse section through the region of the abdominodorsals.

The *lateral channels* found one on each side of the alimentary canal possess muscular walls and are contractile; the fluid within them flows from the posterior to the anterior side. At the posterior end, both these channels open into the dilation of the ventral channel. In the 5th segments, the two lateral channels break up into capillaries. *The lateral channels are distributing as well as collecting channels.* Each lateral channel receives two branches

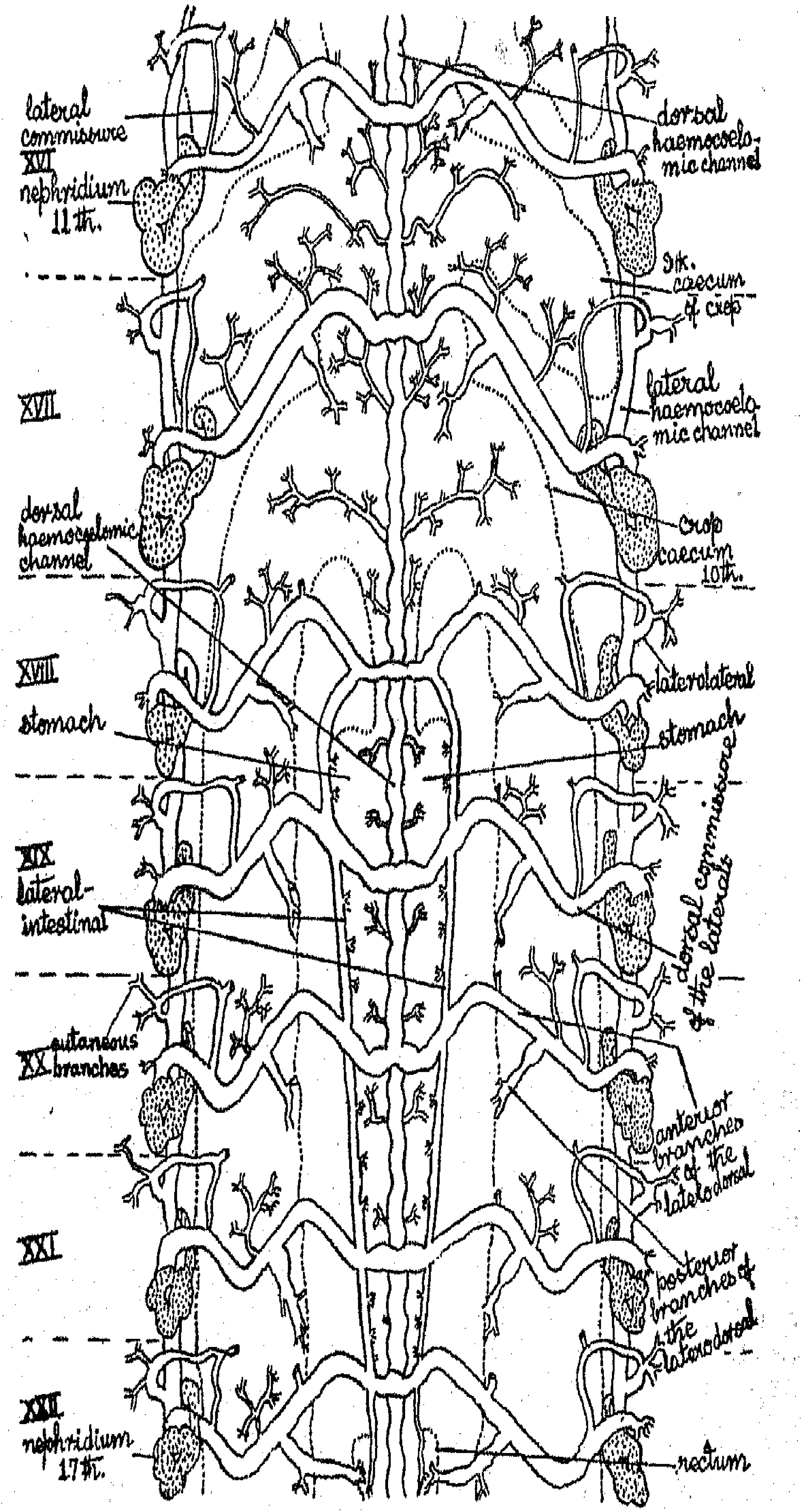
lateral commissure
XVI
nephridium 11th.
XVII
dorsal haemocoelomic channel
XVIII
stomach
XIX
lateral-intestinal
cutaneous branches
XX
XXI
XXII
nephridium 17th.
dorsal haemocoelomic channel
9th. caecum of crop
lateral haemocoelomic channel
crop caecum 10th.
laterolateral
stomach
dorsal commissure of the laterals
anterior branches of the laterodorsal
posterior branches of the laterodorsal
rectum

Fig. 210. The haemocoelomic system in the seven segments 6th to the 12th (Based on Bhatia).

and sends out one branch in each segment (See fig. 212). The channels received are (i) the latero-lateral and (ii) the latero-dorsal; (iii) *latero-ventral* is the one which arises from the lateral channel in each segment. The *latero-ventral* distributes the fluid to the nephridia, genital organs, gut and the ventral bodywall and the *latero-lateral* and the *latero-dorsal* collect the haemocoelomic fluid from all these parts.

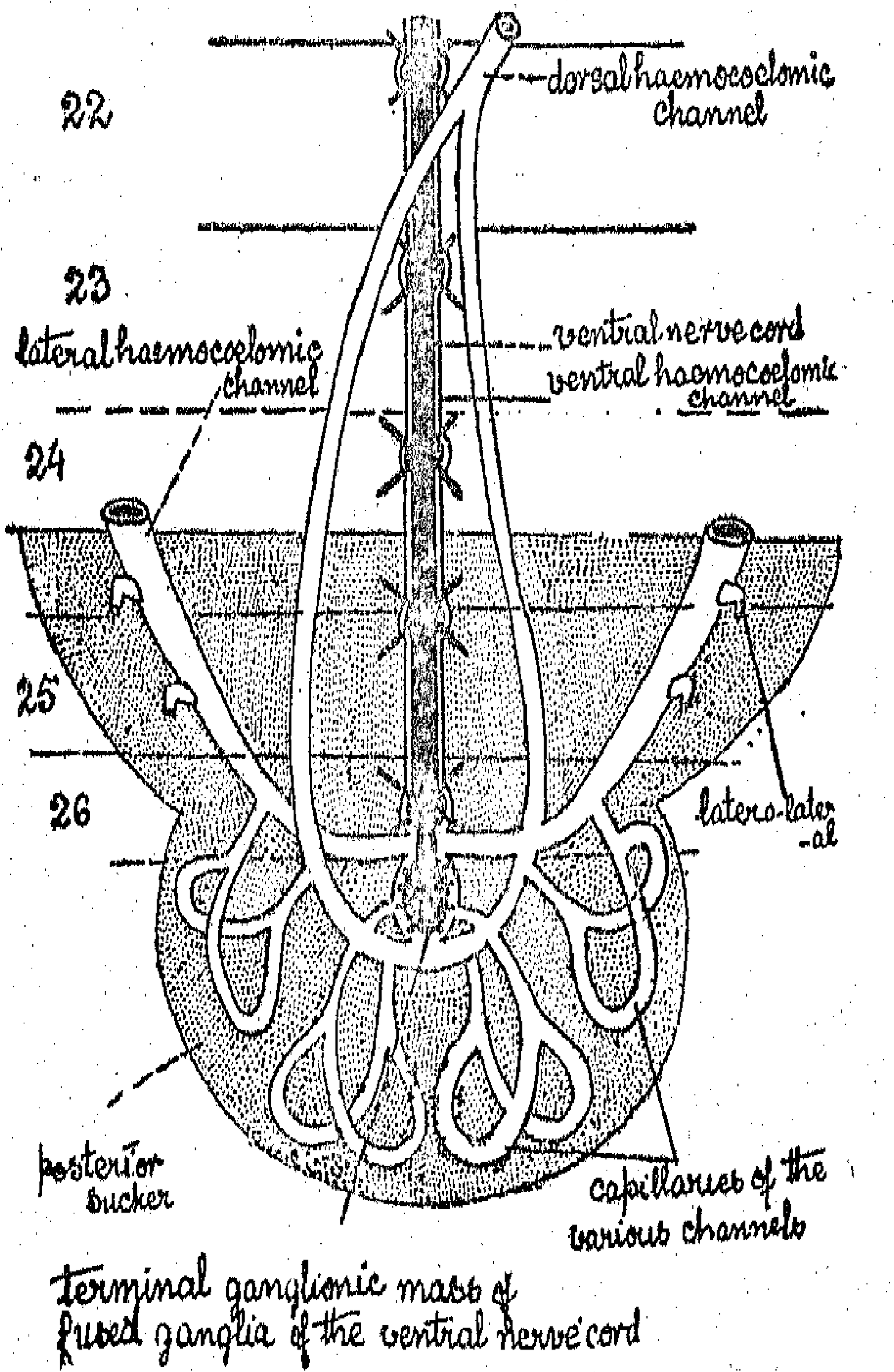
dorsal haemocoelomic channel
22
23
lateral haemocoelomic channel
ventral nerve cord
ventral haemocoelomic channel
24
25
26
latero-lateral
posterior sucker
capillaries of the various channels
terminal ganglionic mass of fused ganglia of the ventral nerve cord

Fig. 211. A diagram showing the place of confluence of the four haemocoelomic channels in the posterior side. (After Bhatia).

Each *latero-dorsal* meets its fellow of the other side and forms a transverse loop over the dorsal channel, the *dorsal commissure.* In all, there are 17 such *dorsal commissures* one in each of the segments 6th. to the 22nd which establish direct communication between the two lateral channels. (See fig. 210).

In each segment a *lateral commissure* connects the latero-lateral and latero-dorsal branches. The (iii) *latero-ventral*, soon after its emergence from the lateral channel, divides into an *anterior* and a *posterior* branch each of which joins its fellow of the opposite side forming a *rhomboid* in each segment which establishes ventrally, a direct communication between the lateral channels. In each of the segments 6th to the 23rd there is one such rhomboid and in all there are 18 rhomboids. A *median* and *two lateral* longitudinal *intersegmental commissurals* join the rhomboids of the successive segments. Prior to its division into two, each lateroventral sends out a branch which supplies the nephridium and the integument. The lateral channels have valves and they supply through their branches to the gut, gonads and the nephridia.

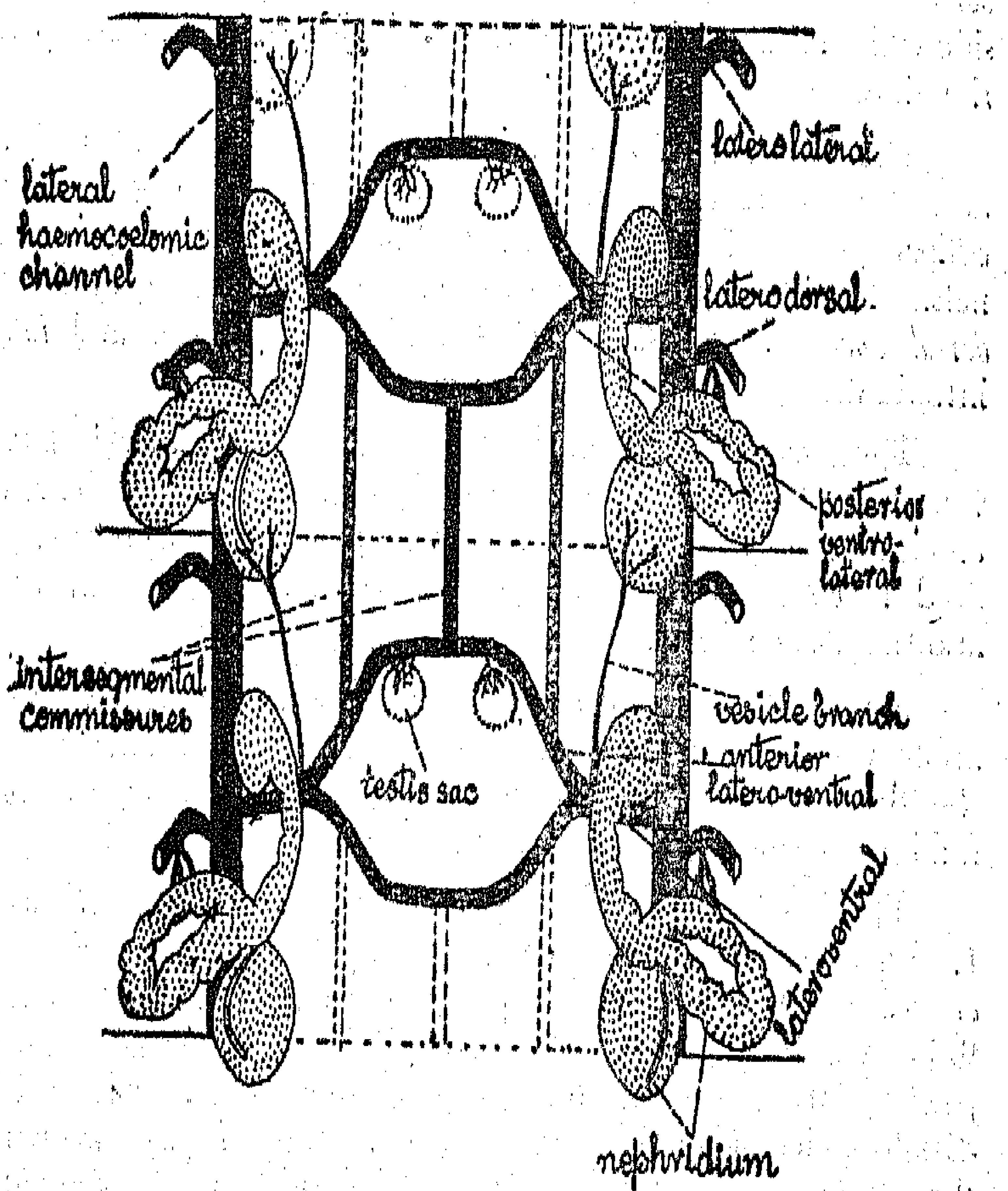

Fig. 212. The lateral channels and their main branches in a segment.

II. The **capillary system** has 3 sets: (i) a fine *botryoidal capillary network* that derives its supply from the ventral channel and covers the viscera; its capillaries finally join the branches of the lateral channels; (ii) the *intramuscular capillaries* which arise from the latero-ventral branches of the lateral channels and also communicate with the botryoidal capillaries and (iii) the *cutaneous capillary plexus* which extends into the epidermis and enters finally the latero-lateral and the latero-dorsal branches. These capillaries communicate with those of the intramuscular set and also with the fine branches of all the four main longitudinal channels.

The capillaries from the stomach and intestine unite forming three intestinal trunks: one *ventral intestinal* and two *ventro-lateral intestinals*; all the three run lengthwise along the gut wall from the 18th to the 22nd segment (See figure on page 247). The ventro-intestinal joins the two lateral channels through small connectives. The ventro-laterals join the latero-dorsals directly.

Course of circulation: The *dorsal* and the *ventral* are the distributing channels but the two *laterals* are both distributing and collecting channels. The direction of flow of fluid in the *dorsal* and the *two laterals* is from the posterior to the anterior side while in the *ventral channel* it is from the anterior to the posterior side.

The *dorsal channel* sends fluid to the alimentary canal and the dorso-lateral body wall. The branches of the *latero-dorsals* collect the fluid from these parts and deliver it to the lateral channels. The fluid from the stomach and intestine goes into the *dorsal commissures* of the laterals through the *ventral* and *lateral* intestinals.

The *ventral channel* supplies to the ventral, lateral, latero-ventral and the median dorsal regions of the body wall, the ciliated organs, nephridia and the atrium; from these regions the fluid is collected into the *lateral channels* through the *latero-dorsals* and the *latero-laterals.*

All the four longitudinal channels communicate with one another at the posterior end. The lateral channels have valves; the fluid flows in a definite direction and the haemocoelomic fluid maintains a real circulation.

There is not found a true blood-vascular system in the leech. Its functions are however performed by the *haemocoelomic system* consisting of elaborate channels containing the red circulating fluid which is really the *coelomic fluid* containing *amoeboid corpuscles*; the coelomic fluid is red due to the presence of dissolved haemoglobin in it. The *red coelomic fluid* known as the *haemocoelomic fluid* is not blood, although it discharges similar functions.

The Excretory System (Nephridial System)

The excretory organs in the leech are the metamerically repeated *nephridia.* One pair of nephridia is found in each segment from the 6th to the 22nd and thus there are in all *seventeen pairs* of them. The nephridia in the segments 12th to the 22nd are described as the *testicular nephridia* because each of these segments has a pair of testes; the nephridia of the segments 6th to the 11th are described as the *pretesticular nephridia.*

From the coelomic end, a *typical testicular nephridium* consists of six parts: (i) the *ciliated organ* (ii) the *initial lobe* (iii) the *apical lobe* (iv) the *main lobe* (v) the *inner lobe* and (vi) the *vesicle duct* and the *terminal vesicle.*

(i) The *ciliated organ* remains completely enclosed within the *perinephrostomial ampullae*; in the adult the *ciliated organ* has absolutely no connection with the body of nephridium and performs no excretory function; instead, the *ciliated organ* manufactures coelomic corpuscles and thus it has become of exclusive service to the haemocoelomic system; it corresponds to the *funnel* of a typical annelid nephridium. The ciliated organ consists of (a) a *central reservoir*, with many perforations in its walls and (b) a very large number of *ciliated funnels* each fitting into a pore in the reservoir. The outer margin and the entire surface of each funnel are richly ciliated.

(ii) The *initial lobe* is made up of a single row of hollow elongated cells placed end to end, through which extends longitudinally a continuous intracellular canal giving out diverticula in each cell. This intracellular canal at the testis sac end ends blindly, while at the other end it joins the canals and canaliculi of the cells of the main lobe very near the place where the vesicle duct originates.

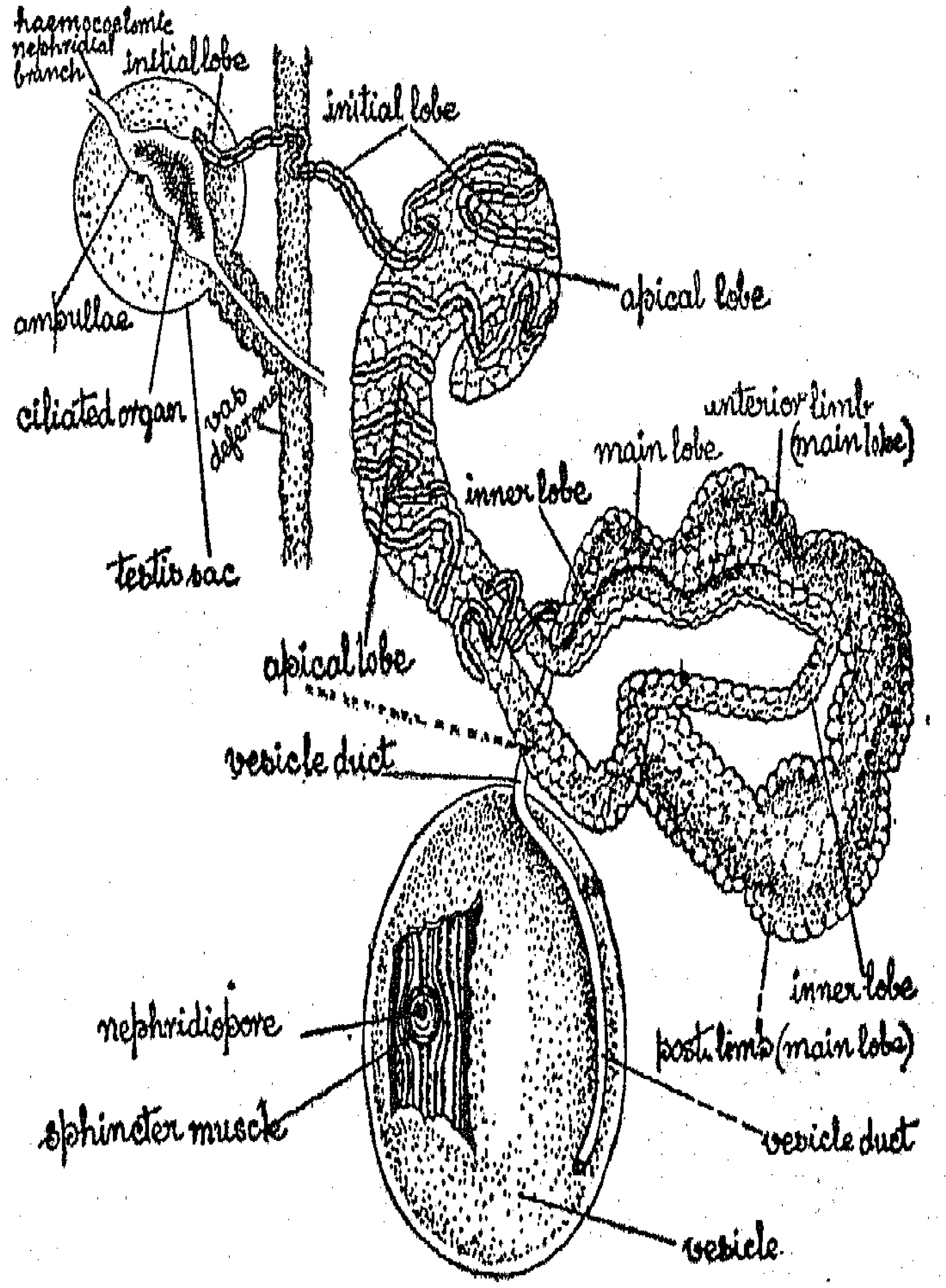

Fig. 213. A complete testicular nephridium showing its parts (Based on Bhatia).

(iii) The *apical lobe* is thick and long and its cells are large and are pierced by large intracellular canals which do not give out diverticula. The thick apical lobe is made up of several rows of cells arranged radially round the central canal; a large number of intracellular canals are found in the apical lobe which form a close net-work traversing the length of the lobe and which open occasionally into the central canal.

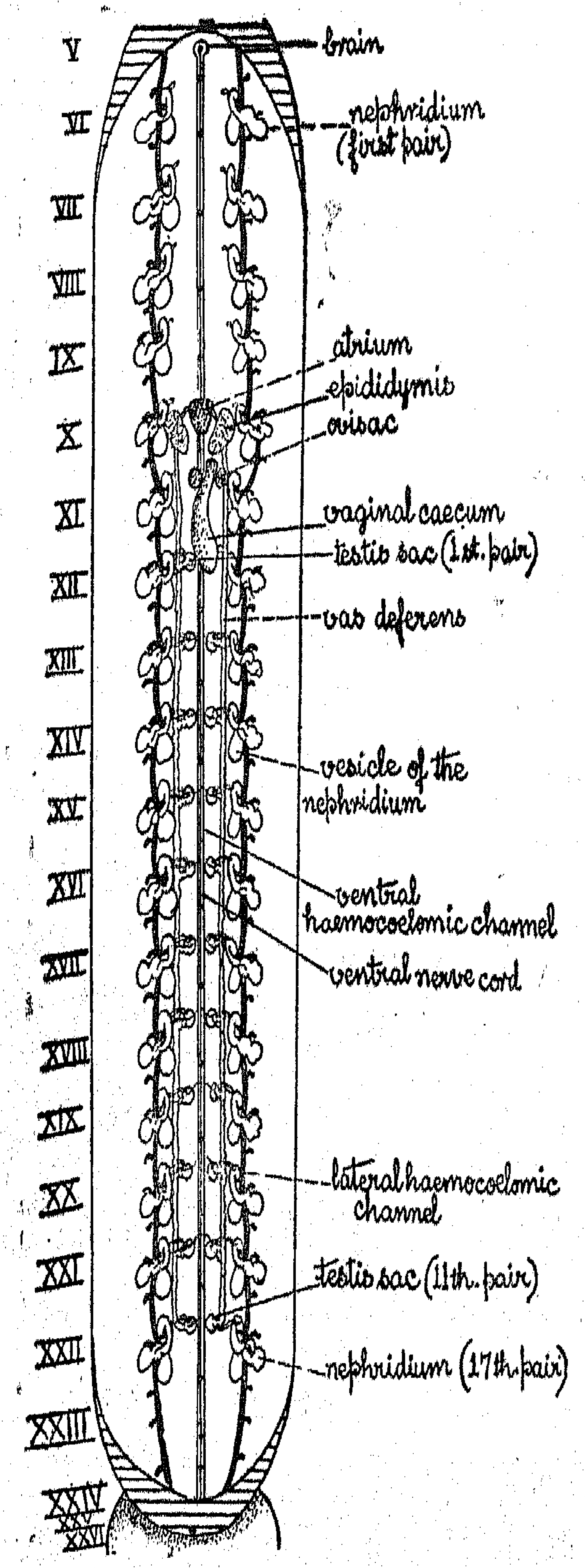

Fig. 214. A dissection of the leech showing nephridial system.

(iv) The *main lobe* possesses large polyhedral cells which are radially arranged around the central canal. Each of these cells possesses a narrow intracellular lumen which branches repeatedly, the branches finally open into the central canal.

(v) The *inner lobe* lies all along the inner concave border of the main lobe and along the outer border of the apical lobe for about half its length. The cells of this lobe are long and tube-like enclosing a large lumen ; five or six such cells surround the intracellular canal.

(vi) The *terminal vesicle* is a large oval thin walled sac which remains full of excretory fluid. From the lower end of the anterior limb of the main lobe starts the nonciliated *vesicle duct* which is a continuation of the central canal of the main lobe ; the vesicle duct extends almost the whole length of the vesicle on its mesial side. The vesicle leads into a short and narrow nonciliated canal which opens to the exterior through the *nephridiopore*. The vesicle has an internal lining of ciliated epithelium.

Inside the nephridium, the excretory fluid has to pass through a long *intracellular canal* which has the following course : full length of the *apical lobe*→*its* posterior end→inner lobe→posterior border of anterior limb of main lobe→passes to the outer border of the apical lobe→becomes imbedded in the apical lobe→length of the apical lobe to its posterior end→main lobe→vesicle duct.

The *nephridium proper* eliminates the excess of water and nitrogenous waste materials from the haemocoelomic fluid (of which *it* gets a copious supply) ; a large quantity of water which is absorbed through the skin of the animal tends to dilute the haemocoelomic fluid but simultaneously the nephridia eliminate the excess water and thus *regulate the osmotic relations of the haemocoelomic fluid and the tissues*.

The excretory fluid which collects in the terminal vesicle is discharged to the exterior through the nephridiopore. (On the ventral surface, in all segments from the 6th or the 22nd, on the last annulus of each are found paired *nephridiopores* ; there are 17 pairs of nephridiopores in all.) Probably the botryoidal tissue also performs an excretory function because the botryoidal capillaries communicate with the haemocoelomic channels.

THE NEPHRIDIAL SYSTEM OF NEREIS, PHERETIMA AND HIRUDINARIA COMPARED

Nereis	Pheretima	Hirudinaria
1. The excretory organs are the metamerically repeated pairs of *nephridia*.	1. The excretory organs are the metamerically arranged *nephridia*.	1. The excretory organs are the metamerically arranged *nephridia*.
2. All the *nephridia* are similar.	2. The nephridia are of three kinds :	2. The nephridia are of two kinds.

Nereis	Pheretima	Hirudinaria
	(i) the *septal* (ii) the *integumentary* and the (iii) pharyngeal nephridia; these differ in size, location and structure e. g. the integumentary and the pharyngeal nephridia have no funnel or neck.	(i) *Pretesticular* and (ii) *testicular*, the two resembling in structure except that in the former i. e. (i) there are no haemocoelomic ampullae and ciliated organs; their initial lobes end loosely within the general connective tissue on each side of the ventral nerve cord.
3. The nephridia are found in all segments of the body with the exception of several at the anterior and posterior body ends.	3. The nephridia are found in all segments of the worm except the first three.	3. The first five and the last four segments have no nephridia. There are in all 17 pairs of nephridia, one pair in each of the segments 6th to the 22nd.
4. The nephridium consists of two parts: (i) a ciliated bell or funnel, the *nephrostome* and (ii) the *body*. The nephridium opens into the coelom by the *nephrostome*. The nephridia and the coelomoducts are closely associated forming the metanephromixium. In case of *Nereis*, part of the coelomoduct becomes separated off from the metanephromixium and becomes attached to the dorsolateral muscles as the *ciliated organ*. The ciliated organ has no excretory function.	4. The structure of the nephridium is more complex and the parts of a full nephridium (e. g. a septal nephridium) are (i) a *ciliated funnel* or *nephridiostome* (ii) a *neck* (iii) the *body* (iv) the *terminal excretory duct*. The *nephridia* and the *coelomoducts* remain separate. The nephridia are *metanephridia*, the nephridium opens into the coelom by a *nephrostome*, the open ciliated end The nephridia in the adult *Pheretima* are the *meronephridia*, for, they are formed by division of the original (large) *holonephridia* into many small nephridia.	4. The structure of the nephridium is still more complicated; a typical nephridium consists of (i) the *ciliated organ* (ii) *initial lobe* (iii) *apical lobe* (iv) *main lobe* (v) *inner lobe* and (vi) *vesicle duct* and the *terminal vesicle*. The ciliated organ corresponds to the *nephridiostome* of the typical annelid nephridium but in the leech it has absolutely no excretory function and has completely separated from the main mass of the nephridium.
5. The nephridia are all *exonephric*, i. e. they open to the outside of the body. The nephridiopore of each nephridium is a fine circular aperture capable of being widened or contracted. The enteronephric nephridia are completely lacking.	5. Some nephridia are *exonephric*, i. e. they open to the outside, while others are *entronephric* i. e. they open into the gut. In *Pheretima*, there are three different types of nephridia: (i) *enteronephric meronephridia* in segments 4, 5 and 6 opening into pharynx; they are called *peptonephridia* and may have a digestive function; (ii) *exonephric meronephridia* (the integumentary ones) found in each segment posterior to the sixth; and (iii) small *meronephridia* (septal nephridia in all segments behind 15th), which open into a pair of ducts found along the dorsal wall of intestine, these ducts have segmental openings into the gut and hence these nephridia are also enteronephric.	5. The nephridia remain separate from the coelomoducts; the nephridia are much like the metanephridia of *Pheretima* but here they are more specialised due to the reduction of coelom; the nephridial canal is very much coiled.

Nereis	Pheretima	Hirudinaria
6. The nephridium lies in two segments, the ciliated funnel or the nephrostome lies in the segment next in front of that in which the body of the nephridium lies.	6. The nephridia are unisegmental in case of the septal nephridium for instance, the funnel, the body as well as the terminal duct lie in the same segment.	6. The nephridia are all unisegmental.
7. Inside the nephridium is found a canal, ciliated except in its most external part which extends through the anterior prolongation to its extremity where it bends back, pursues a winding course to the outer end and then again runs forward to open by the *nephrostome*. The canal is an excavation in a mass of nucleated material not distinguishable into cells.	7. The body of the nepridium has two main parts: a *straight lob* and a spirally *twisted loop*. The funnel leads into a *narrow ciliated tubule* which forms a very long and looped nephridial canal. The course of nephridial canal in the body is complicated and the canal has *four ciliated tracts* in the body of the nephridium.	7. The nephridium consists of the initial lobe, the apical lobe, the main lobe, the inner lobe, vesicle duct and the vesicle. The main channel for the excretory fluid is the *intracellular canal* which follows a tortuous course throughout the body of the nephridium and then emerges as the vesicle duct which runs along the length of the vesicle and becomes attached to it. The central canal as well as the vesicle duct are non-ciliated. The vesicle alone is lined internally with a ciliated epithelium.
8. The nephrostome opens into the coelom.	8. The ciliated nephrostome opens into the coelom.	8. The *ciliated organ* which corresponds to the 'funnel, or *nephrostom*: in the adult loses connection with the nephridium; the nephridium does not open into coelom.
9. The nephridium extracts waste products from the blood and the coelomic fluid.	9. The waste products are excreted by nephridia both from the coelomic fluid and blood. The waste products are *ammonia*, *urea* and *creatinine*.	9. In *Hirudinaria*, the only fluid found is the *haemocoelomic fluid* of which the nephridium receives a copious supply from the lateral and the ventral channels. From the fluid, excess of water and nitrogenous waste are eliminated.

Reproductive System in Hirudinaria

The leech is hermaphrodite and cross fertilization occurs by conjugation of two leeches which may occur in water or on land.

The **male system** consists of eleven pairs of *testis sacs*, the *vasa efferentia*, the *vasa deferentia*, the *epididymes*, the *ejaculatory ducts* and the *atrium*. Each testis sac is in fact a spherical coelomic sac containing colourless coelomic fluid; the walls of the testis sac bud off spermatogonia which develop in the coelomic fluid contained in the testis sac. A pair of testis sacs lies in each of the segments from the XII to the XXII, one on either side of the ventral nerve cord so that there are *eleven pairs* of *testis sacs*. From each testis sac arises posteriorly a short *vas efferens* which joins the vas deferens of its own side. The *vasa deferentia* extend forward from the XXII to the XI segment on either side of the ventral nerve cord. The vasa deferentia are enclosed within tubular coelomic spaces which contain coelomic corpuscles.

Each vas deferens bends inward in the X segment and forms a closely convoluted compact *epididymis* or *sperm vesicle*; from the inner end of each epididymis arises anteriorly a short narrow *ejaculatory duct* which leads into a median pyriform sac, the *atrium* which lies in the ninth and tenth segments. The *atrium* has (i) an anterior thick walled and muscular *prostate* covered over with a number of unicellular *prostate glands* each opening into the prostatic chamber by means of a duct; and (ii) a posteriorly placed *penis sac* which contains a coiled filamentous eversible *penis* which can protrude out through the male generative opening situated within the groove between the 2nd and 3rd annuli of the X segment on the ventral side in the median line. The spermatozoa manufactured in the testis sacs travelling through the *vasa efferentia* and the *vasa deferentia* reach the epididymis where they are temporarily stored: thereafter the sperms get into the prostatic chamber where getting glued together by the viscid prostatic secretion they form bundles of spermatozoa known as *spermatophores*. During **copulation**, when the everted *penis* gets inserted into the *vagina* of the female, the spermatophores getting through the slender canal of the penis pass into the vagina of the other leech.

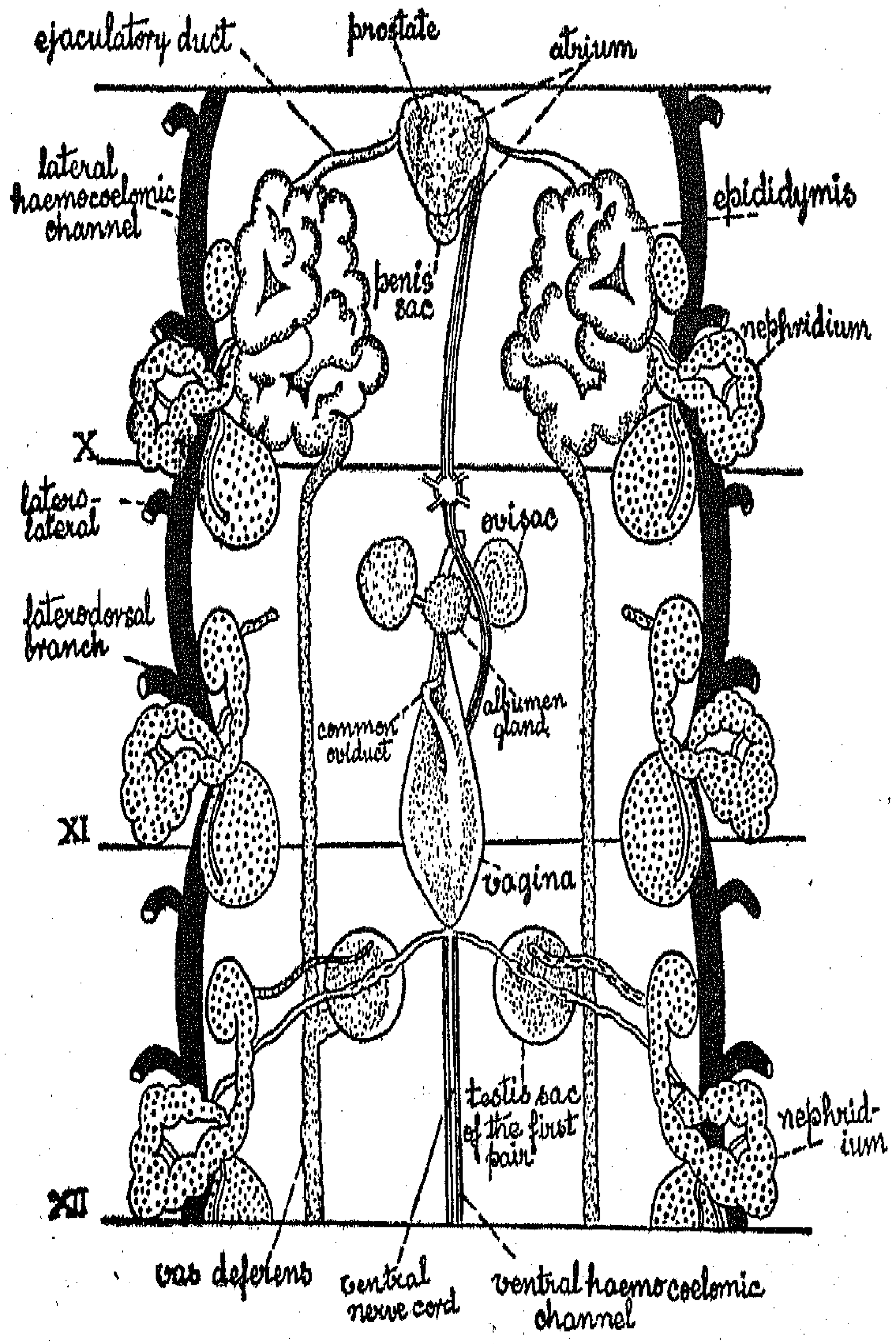

Fig. 215. The reproductive organs of Hirudinaria (Redrawn after Bhatia).

The **female system** consists of a pair of *ovisacs*, a pair of *oviducts*, a common oviduct and a median *vagina*. The ovisacs situated in the XI segment are a pair of coelomic sacs; each ovisac contains a coiled *ovary* which remains floating in the coelomic fluid contained within the ovisacs. A short slender oviduct arises from each ovisac and the two oviducts unite and form a *common oviduct* in the XI segment: the union of the two oviducts is imbedded in the unicellular *albumen glands* which open into the lumen of the common oviduct. The S-shaped posterior part of the common oviduct opens posteriorly into a large pearshaped muscular *vagina* lying in the posterior region of the XI segment. The vagina opens to the outside through a narrow duct that leads to the *female generative aperture* on the ventral surface of the leech within the furrow following the second annulus of the XI segment. After copulation, fertilization occurs within the vagina and the fertilized ova are shed into the cocoon through the female generative aperture.

During **copulation** (which occurs in the months of March and April), two worms contact on their ventral sides in a head to tail position so that the male aperture of the one lies against the female aperture of the other. The *penis* of one partner is inserted into the *vagina* of the other. The copulation lasts for about an hour which is a rather long period for the coition after which the seminal discharges occur resulting in reciprocal fertilization. Afterwards the participants detach. The cocoons are laid in April, May and June amongst lumps of clay or within the crevices by the side of a pond; the cocoon floats in water due to the enclosed air bubbles. The barrel shaped cocoon has at each of its ends a *polar plug*. The development occurs within the cocoon which contains one to twenty four embryos besides albumen which is consumed as food by the developing young ones. The polar plugs are dropped off at the conclusion of the developmental process to set free the young leech from the confinement of the cocoon.

The *cocoon* as well as the *albumen* are secreted by the clitellar glands of the clitellum; the polar plugs are secreted by the prostomial glands. The fertilized ova are extruded through the female aperture into the albumen of the girdle; the worm then withdraws its preclitellar region into the cocoon so that the prostomium lies just within the anterior pole of the cocoon. Now the prostomial glands secrete the *anterior polar plug*; after its completion the worm withdraws still more keeping its anterior end at the posterior pole of the cocoon and now the *posterior plug* is similarly formed. Finally the leech leaves the cocoon which has a chitinous wall and a light yellow colour. The outer thick spongy layer of the cocoon is protective in function; the inner membranous layer is probably cuticular.

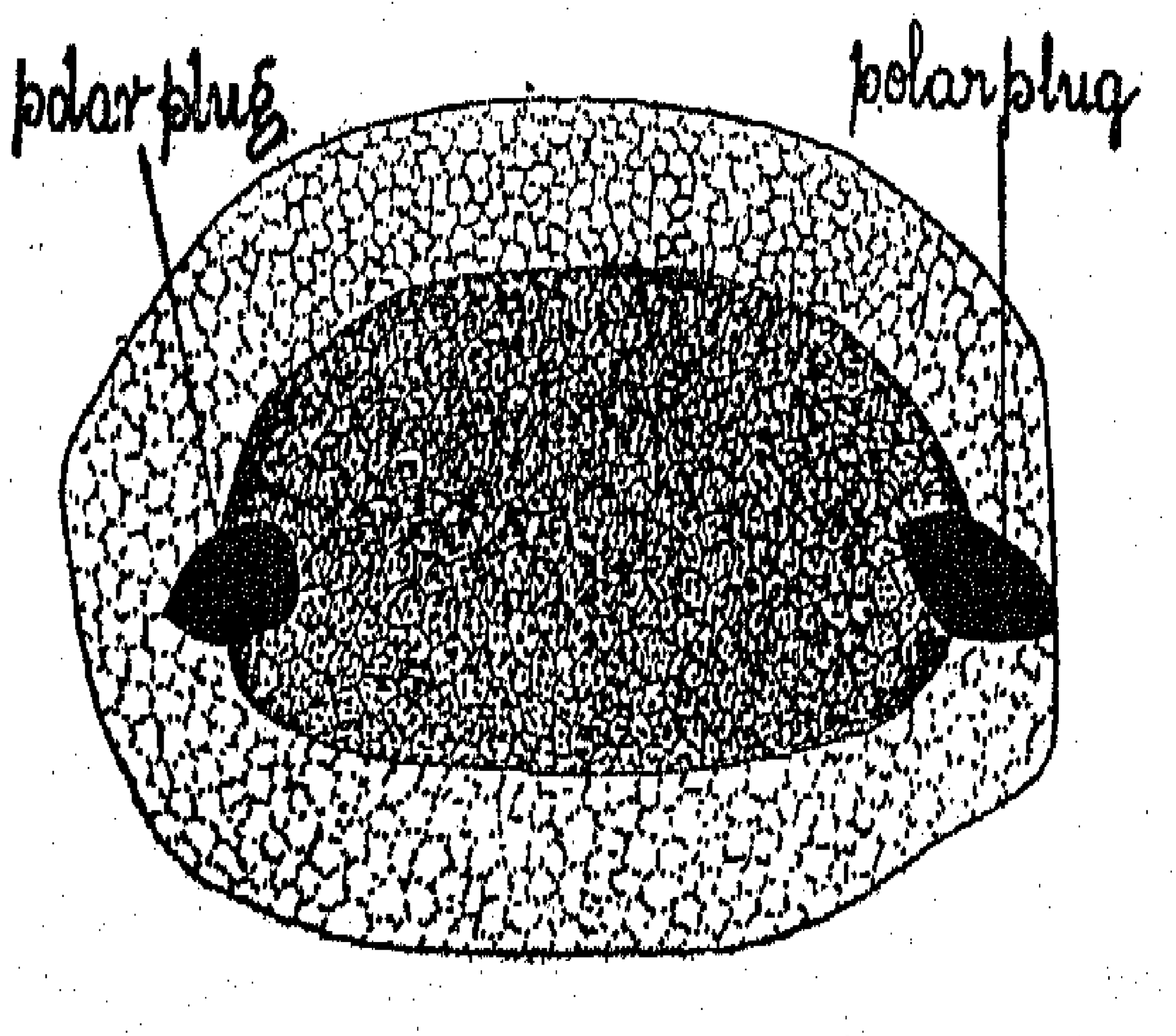

Fig. 216. Longitudinal section of a cocoon (Redrawn after Bhatia).

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Classification of Annelida

The phylum **Annelida** is divided into the following seven classes of which the first three are more important. Names of the important members are also being given below :

Class I.	**Polychaeta** :	*Nereis*, *Aphrodite*, *Arenicola*, *Chaetopterus*.
Class II.	**Oligochatea** :	*Pheretima*, *Eutyphoeus*, *Allolobophora* ; *Nais* and *Dero* which are the two aquatic forms.
Class III.	**Hirudinea** :	*Hirudinaria*, *Glossiphonia*, *Pontobdella* and *Branchellion*.
Class IV.	**Archiannelida** :	*Saccocirrus* (Not to be described in this book).
Class V.	**Echiuroidea** :	*Bonellia*.
Class VI.	**Sipunculoidea** :	*Sipunculus*.
Class VII.	**Priapulida** :	*Priapulus* (Not to be described in this book).

Class I. **Polychaeta** mostly *marine*, with a distinct *head* bearing a few appendages, well segmented, the spacious coelom is partitioned by intersegment septa ; *chaetae* arise from distinct muscular prominences of the bodywall called parapodia ; mostly unisexual, gonads extend throughout the body, fertilization external ; no clitellum, a free swimming *trochophore larva*+which undergoes metamorphosis.

Aphrodite '(Sea-mouse)' burrows in mud at the bottom of sea ; segmentation not clear on the dorsal side ; on the ventral side segmentation is very clear. It covers its dorsal side with a felt formed of interwoven chaetal threads of the *notopodium* which *itself* becomes reduced.

Between this felt and the back is a space into which water is drawn by a pumping action of the dorsal bodywall. The water is filtered through the blanket. Between the blanket and the *bodywall* i. e. covering the *latter* are found plate like modifications of the dorsal cirri known as *elytra* round which the water circulates from which the animal derives dissolved oxygen. The elytra are found on alternate segments and present an imbricate arrangement. The *parapodia* are biramous, the neuropodium is like that of *Nereis* but the *notopodium* is much reduced. The notopodial setae are highly modified and are of three kinds : (i) very long and hairy chitinous threadlike setae which get interwoven to form the blanket at the back, (ii) iridescent setae and (iii) short stiff retractile setae. When the animal is irritated, these spine-like bristles are erected so that it looks like a miniature porcupine. In shallow waters when the sunlight falls upon the animal, the hair covering displays a rainbow of colours. The *prostomium* bears a small *median palp* and two *lateral palps*.

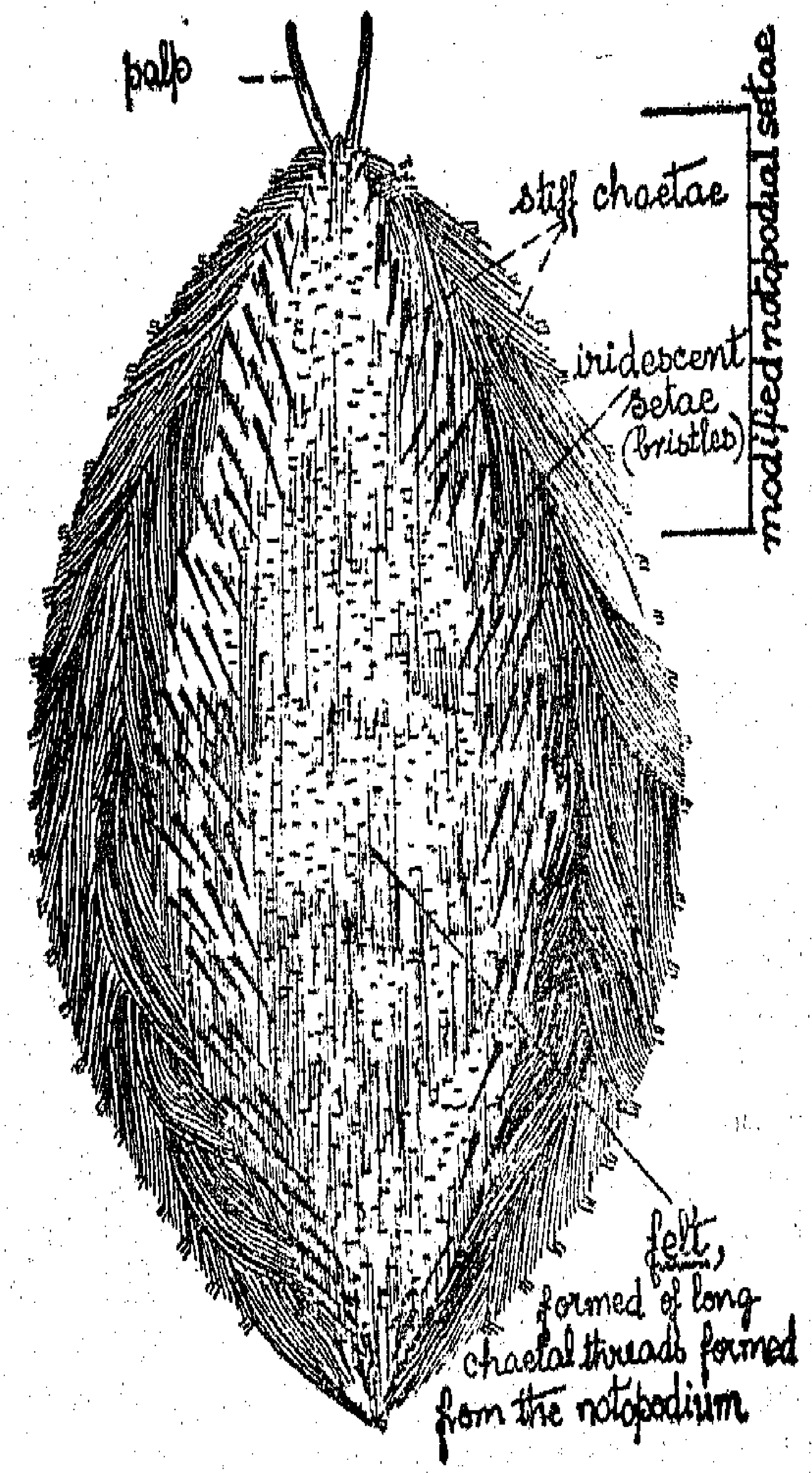
palp
stiff chaetae
iridescent setae (bristles)
modified notopodial setae
felt, formed of long chaetal threads formed from the notopodium

Fig. 217. Aphrodite (Dorsal view).

Arenicola (lug worm) lives in burrow open at both ends, devours sand containing minute organic particles ; the prostomium is much reduced and bears no appendages. The *eversible pharynx* is covered with minute papillae and helps in feeding and locomotion. The body is divisible into three regions : (i) the **anterior region** consisting of an achaetous prostomium and the first six segments provided with notopodia with capillary setae and a neuropodial ridge with uncini-like chaetae ; (ii) the **middle region** which has very small setae and no parapodia, only the cirri are retained which are modified into *gills* or *branchiae* and

(iii) the *posterior region* which lacks both parapodia and chetae. There is a spacious perivisceral coelom but only three septa are found in the anterior region and some in the posterior region and the coelom is continuous for its greater part.

Chaetopterus is the most modified truly tubicolous[1] worm. The worm lives in a parchment tube of its own making which is for the most part buried in the sand with only a small part of it projecting above. Both the ends of the tube are open and it is the open ends which remain projecting a little above the sea-floor. The worm lies completely within the tube. The animal is luminiscent. The **body** has three regions: (i) an **anterior part** including the prostomium and the first *nine* segments, (ii) a **middle region** including five segments and (iii) a posterior part consisting of the last thirty segments.

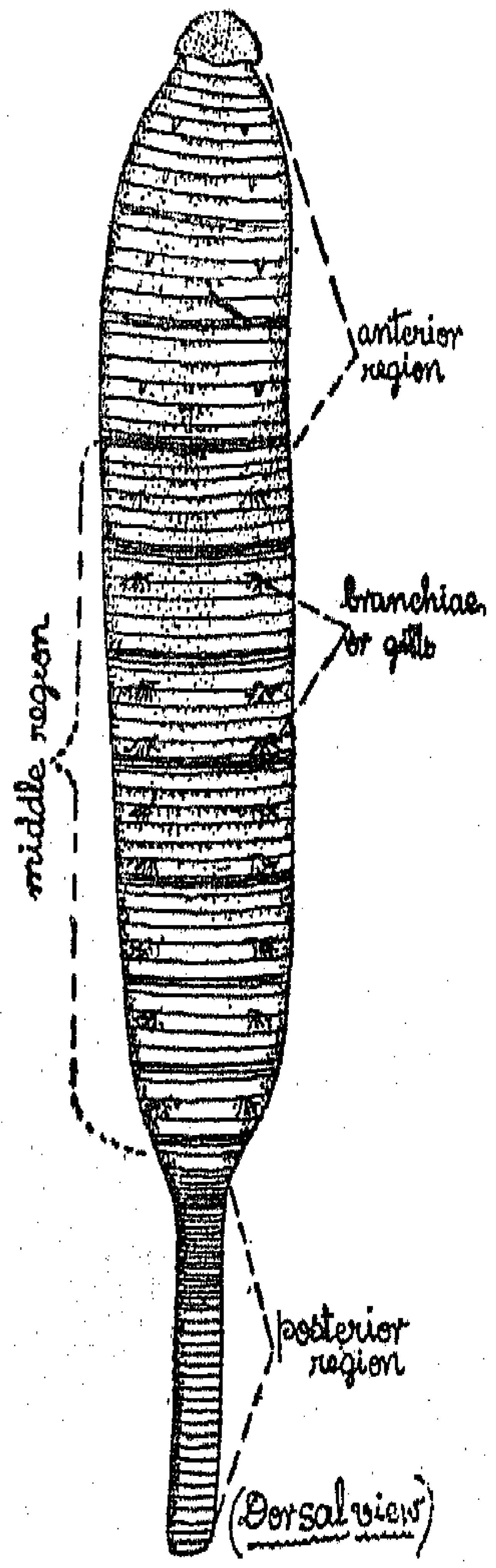

Fig 218. Arenicola marina.

The *anterior part* forms a trap for the tiny food-organism, the *middle region* has fan-like equipment of creating a strong and steady current of water and the posterior part is mainly reproductive in function. The worm fits sufficiently loosely in its tube so that there is plenty of room for the water current to sweep through from one end to the other. The *prostomium is reduced* and there are two peristomial tentacles. The anterior region is broad and funnel shaped. The *segments up to nine bear conical parapodia.* The *tenth notopodia are large* wing-like. The parapodium of the 12th segment (the middle region) of the body is modified into a sucker-like structure. The parapodia of the 13th, 14th and 15th segments are membranous and fan like; they beat up and down and create the food and respiratory water current. The food particles in the water current are caught in mucus secreted by the dorsal surface of the anterior region; the ciliary currents working in grooves in the enlarged notopodia of the tenth segment convey the mucus strings to the cup shaped organ where a ball of food is formed; the food-particles are entangled in the mucus bag and form a *bolus* in the cup at the end of the mucus bag; the ball of food is carried forward in a dorsal groove due to action of cilia to the mouth. Large particles of food however fall directly into the buccal funnel.

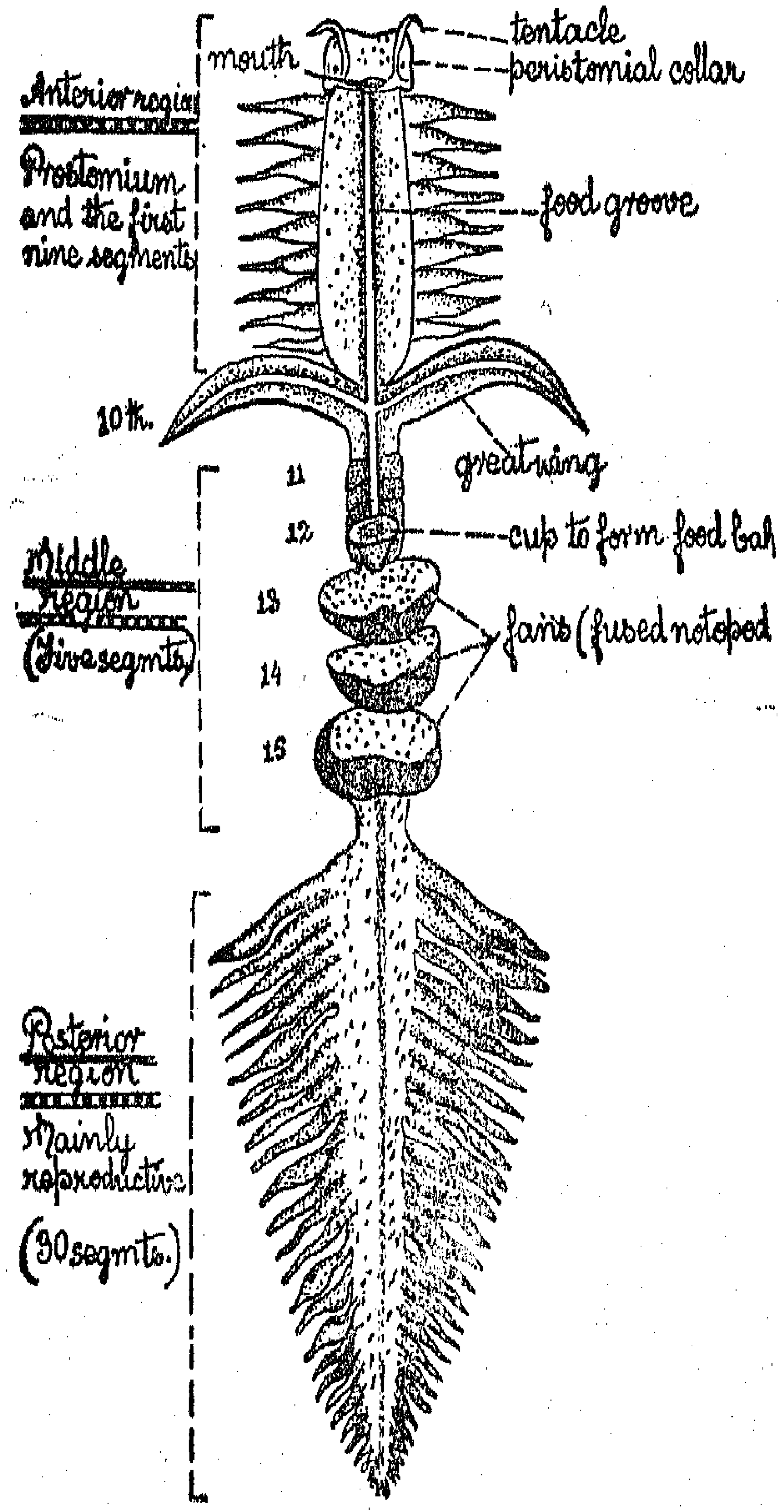

Fig. 219. Diagram to illustrate the structure and feeding of Chaetopterus.

Class II. **Oligochaeta**: worms with a small number of chetae, parapodia are absent, the head is not well-marked but there is a distinct pre-oral lobe or *prostomium* which lacks appendages; are hermaphrodite, the gonads are localised and only a few in number occurring in fixed segments in the anterior region. The coelomoducts function as genital ducts and open by funnels into the coelomic cavity; *spermathecae* and *clitellum*+the eggs are deposited in a cocoon, the development is direct and there is no larval stage. In obligochaetes degeneration of eyes, palps and other appendages is considered to have occurred due to specialised burrowing habit. The sense organs have become reduced. The class includes 2 orders (i) *Terricolae* including terrestrial forms;

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[1] [*Tubicolous*, inhabiting a tube].

Eutyphoeus, Lumbricus, Allolobophora and *Pheretima* and (ii) **Limicolae** including aquatic forms e. g. *Nais, Dero.*

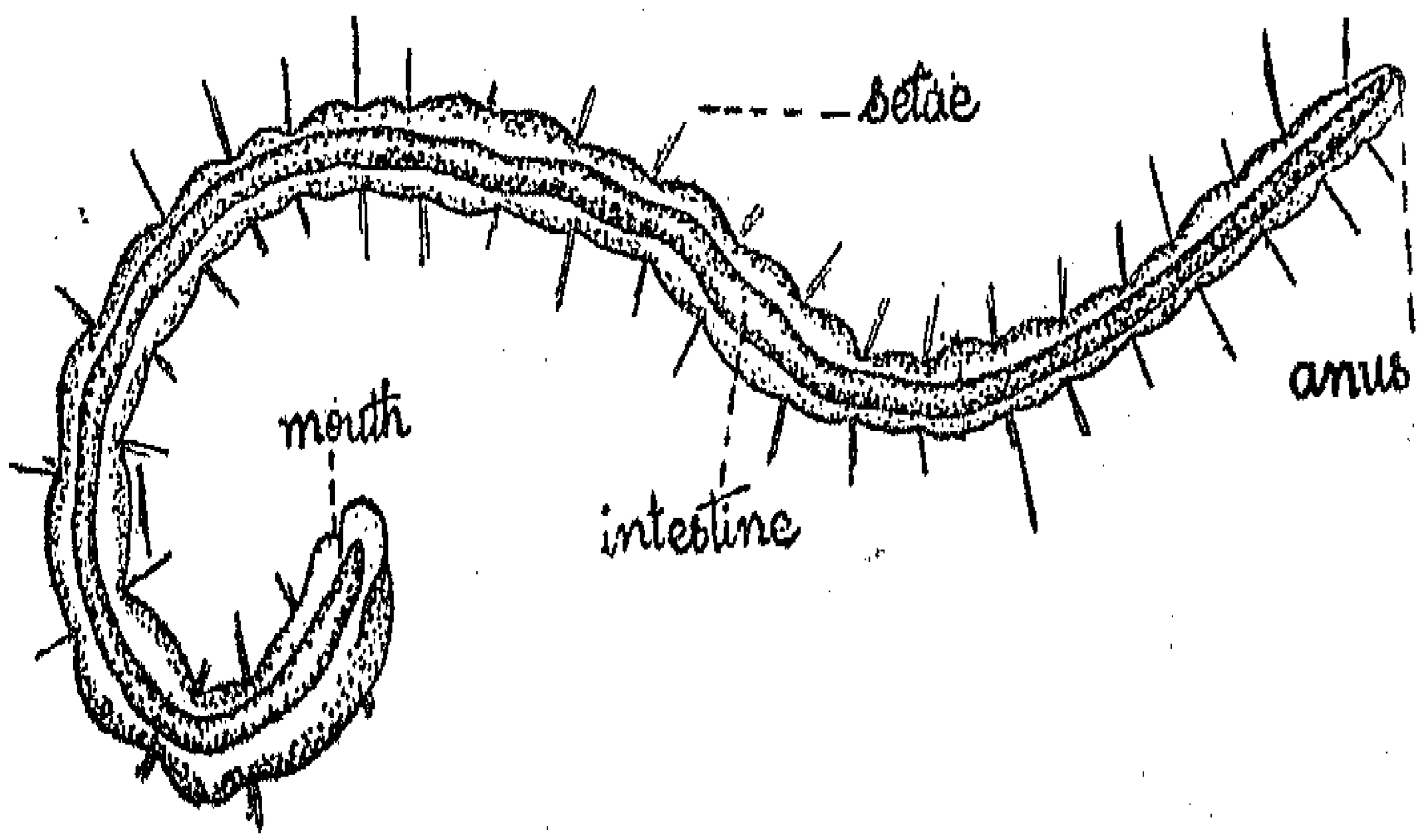

Fig. 220. Nais sp.

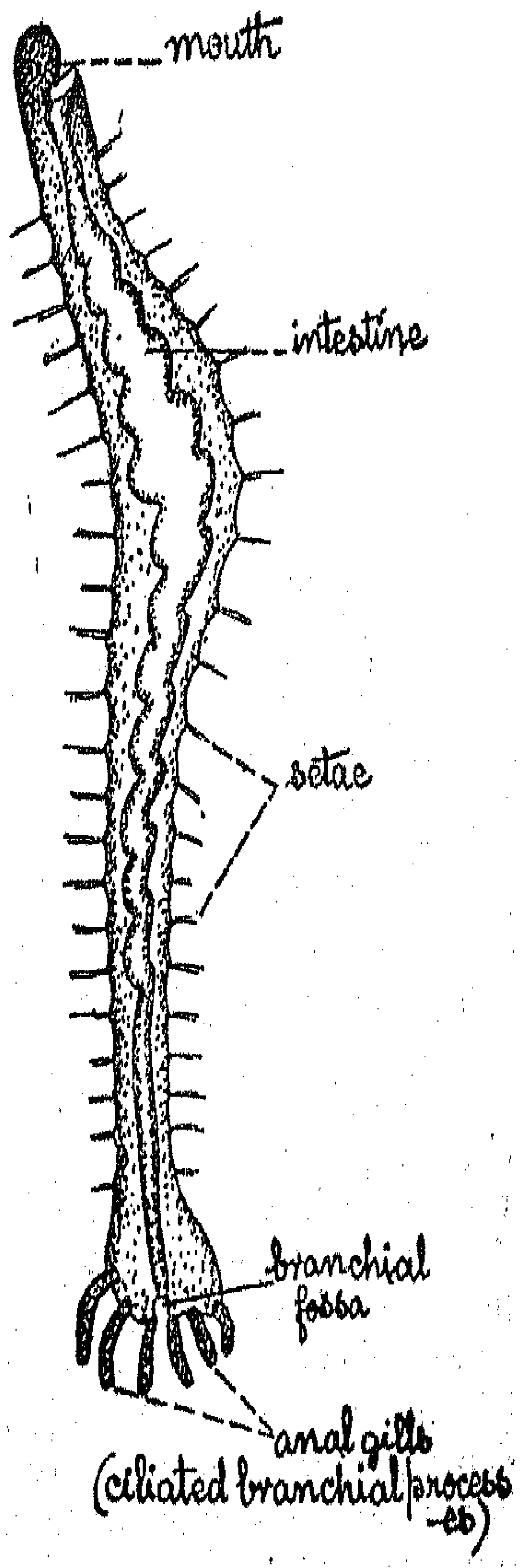

Fig. 221. Dero.

Nais is 2 to 4 m. m. long, has 15 to 37 segments reproduces asexually by transverse fission. Sexual reproduction is not well developed. Setae occur in 4 bundles, two dorsal and two ventral; the setae of the dorsal bundles are long.

Dero has at its extreme posterior end a small depression called branchial fossa from the margin of which arise finger like or plate like ciliated processes which surround anus and contain loop like blood vessels; their cilia produce a water current for renewal of water. Their blood gets aerated and they are known as **anal gills** due to their respiratory function.

Class III. **Hirudinea**: segmented worms having a small and fixed number of segments; the external annuli are much more numerous than the true segments; *both chaetae and parapodia are absent.* Several segments at the anterior and posterior ends are modified to form an anterior and a posterior sucker respectively; are hermaphrodite, embryo develops in a *clitellum.* *Coelom* is much reduced and is largely encroached upon by the mesenchymatous tissue,

The coelom is represented in the adult by *haemocoelomic channels,* the *spaces inside testis sacs* and *ovisacs* and certain other spaces. The development is direct and there is no larval stage. The nephridia and the testes are metamerically arranged.

Order (i) **Rhynchobdellida**: both marine and fresh water forms; blood is colourless, the anterior part of the body can be protruded to form a *protrusible proboscis*; no jaws. The mouth is a small median aperture situated within the anterior sucker.

Pontobdella: marine, parasitic on elasmobranch fishes, chiefly affecting sharks, rays and skates. The body surface is rough due to papillae on the surface. The nephridial system is modified and instead of separate nephridia, a complex network is found on the ventral side which gives off on each side of each segment, a *branch* which terminates in a ciliated funnel and another branch which opens to the outside. The worm has *dorsal, ventral* and *lateral* vessels which are enclosed in sinuses.

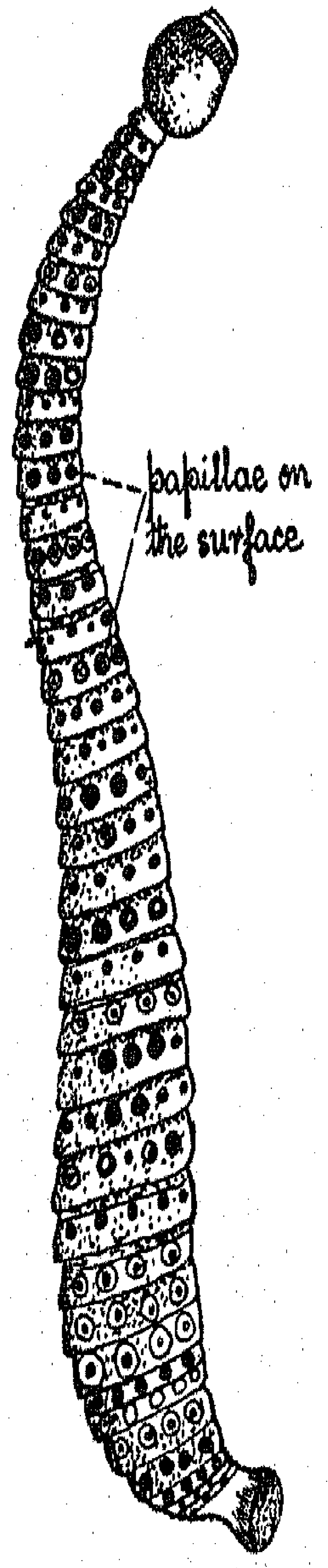

Fig. 222. Pontobdella.

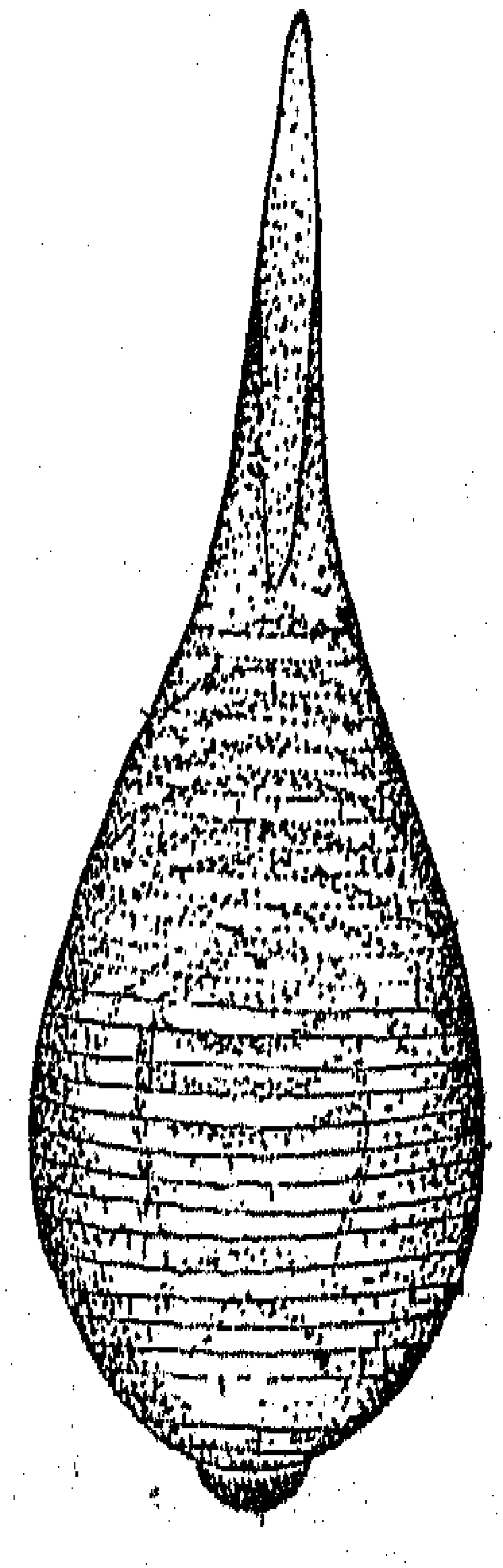

Fig. 223. Glossiphonia.

Glossiphonia (*Clepsine*) is a fresh water leech with an ovate and flattened body; it feeds upon molluscs e. g. *Planorbis, Limnae.* The anterior end of body is narrow and the posterior end is broad. The anterior sucker is fused with the body, the posterior sucker is distinct. The hind gut has four pairs of lateral caeca; the young when hatched get attached to the ventral surface of the mother. The eggs are laid in the spring and are enclosed in membranous sacs fixed to the parent.

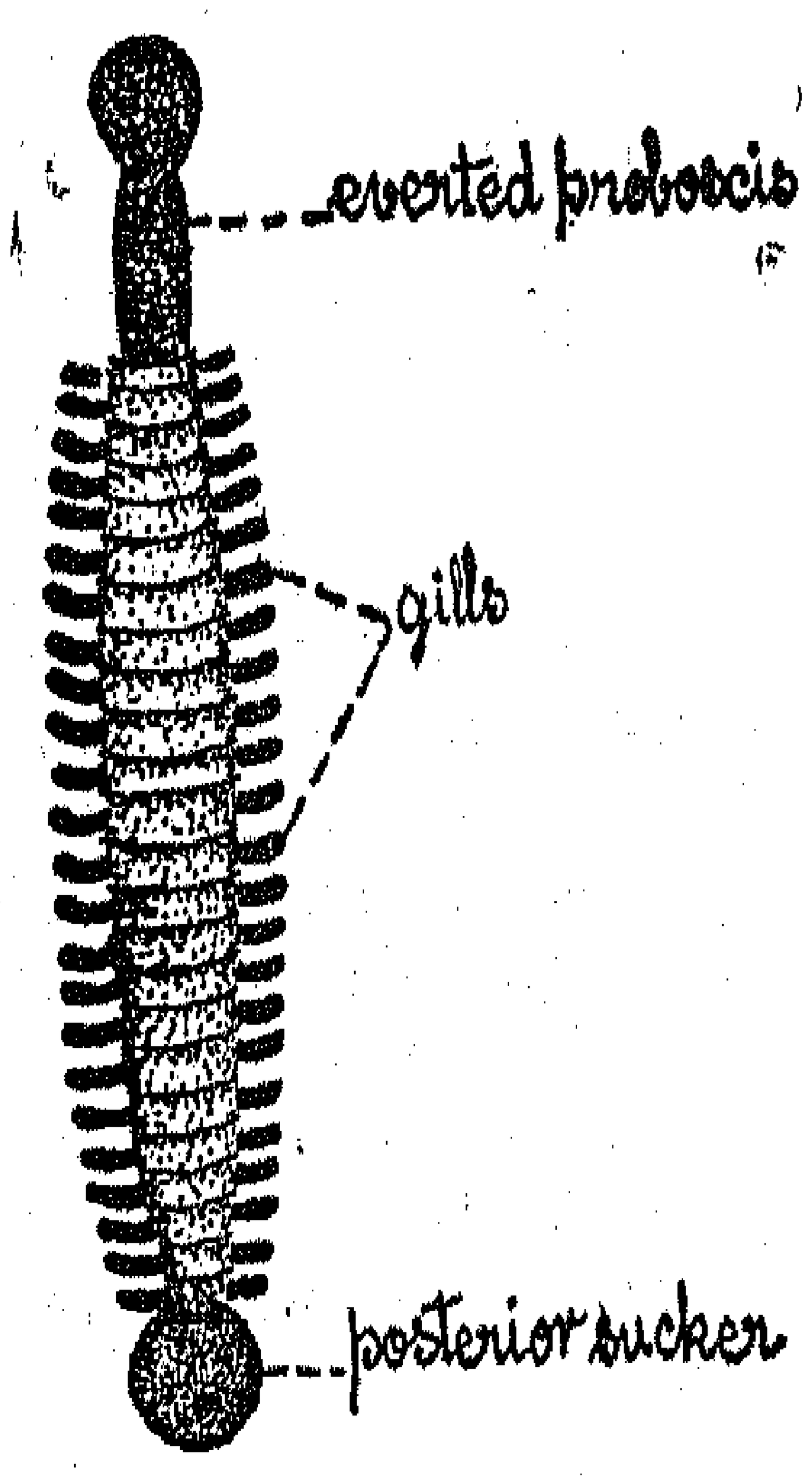

Fig. 224. Branchellion.

Branchellion is marine, parasitic on Electric Rays (*Torpedo*) and on an Australasian skate; *Branchellion* possess delicate lateral outgrowths of the segments serving as respiratory organs and hence known as gills. The nephridial system is modified as in *Glossiphonia*. *Branchellion* is found on the outer surface of the Skate, Electric Ray and other fishes as a permanent ectoparasite.

Order (ii) **Gnathobdellida** include large leeches adapted to a blood sucking predaceous habit; mouth has usually three toothed jaws; freshwater or terrestrial, without a protrusible proboscis, the pharynx is fixed, haemocoelomic fluid red. *Hirudinaria*, *Hirudo* and *Haemopsis*.

Class V. **Chiuroidea**: include small marine worms, unsegmented in the adult condition. Parapodia altogether absent, *chetae*, a single pair on the ventral surface (except in *Saccosoma*). Sometimes several pairs of segmental organs present. At the anterior end, a median appendage, the *proboscis* hangs over the mouth (absent in Saccosoma). The proboscis is not retractile, is sensitive and capable of movements. The coelom is continuous. The gut is much coiled. An elongated tube, *siphon* communicates with the intestine at both its ends and a ciliated groove runs throughout the length of the latter. A closed blood-system is present. There is an unsegmented ventral nerve cord giving out pairs of nerves. No sense organs. A pair of (excretory) *anal vesicles* open into the rectum which have appended to them many ciliated funnels opening into them from the coelom. The sexes are separate and there is a marked *sexual dimorphism*. The larva is a trochophore. *Bonellia*, *Echiurus*, *Thalassema*.

Bonellia: the female is about 2 inches long and has a long extremely extensible proboscis at its anterior end; the proboscis is bifurcated at its terminal end. Along the ventral surface of the proboscis runs a *ciliated groove* convertible into a tube by the approximation of its edges: the groove leads into the mouth at the base of the proboscis. The animal lives in clefts and fissures of rocks and stones with the proboscis projecting out to keep contact with the outerside. When contracted the proboscis is only a few

inches long but when extended it becomes over a metre in length; between the two terminal ends of such a highly extensile proboscis, *Bonellia* seizes bodies of ascidians or other preys which are carried into the mouth along the groove. On the ventral surface, shortly behind the mouth are found two chitinous setae. The alimentary canal is coiled and has a ciliated ventral groove. The alimentary canal has a siphon,—a narrow tube arising from it near the mouth and re-entering it again down below. The branched anal vesicles unite into a common stem which opens into the intestine close to the anus. The free end of these branches terminates in a ciliated funnel shaped opening. The anal vesicle probably perform an excretory function and may also control the amount of fluid in the body cavity. A closed vascular system is present. There is only one nephridium. The nervous system consists of a ventral nerve cord attached to the skin and a circumoesophageal ring which in the proboscis runs along the sides uniting at the top. Brain and sense organs are not differentiated. Certain cells lining the body cavity massed together along the wall of the ventral vessel form the ova. One of these cells grows and becomes the ovum which leaves through the nephridium. Thus the female is the *typical individual.*

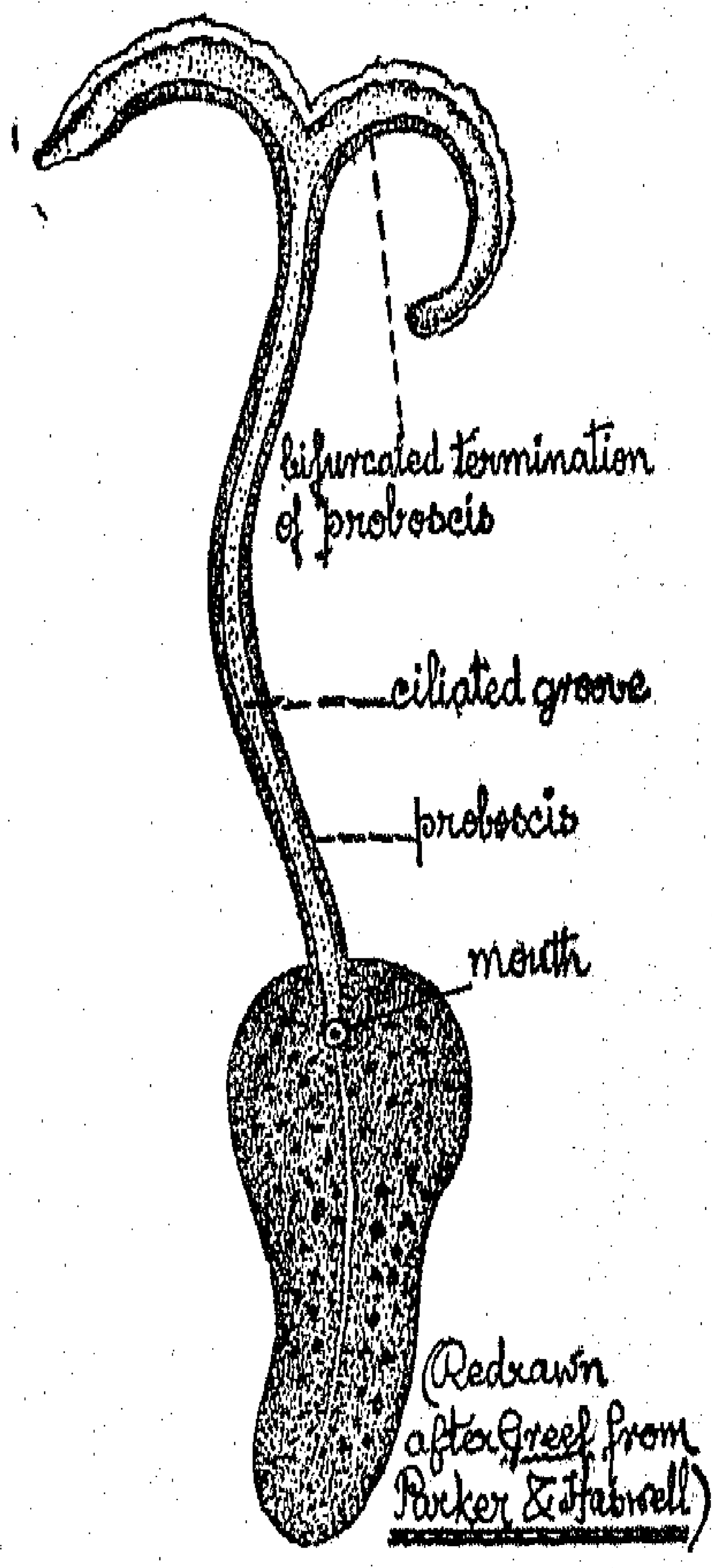
bifurcated termination of proboscis
ciliated groove
proboscis
mouth
(Redrawn after Greef from Parker & Haswell)

Fig. 225. Bonellia viridis (Female).

The male *Bonellia* is however reduced to a small turbellarian like ciliated organism about the size of a *paramecium.* The alimentary canal is reduced. The male when it is young enters the pharynx of the female and established itself permanently in its nephridium. On the ventral surface there is a pair of hook like ventral setae; there is a body cavity which does not reach the two ends of the body. There is a nerve-ring and a ventral cord. Two rudiments corresponding to the anal vesicles of the female are found. There is a single nephridium serving as a duct for the spermatozoa. The larvae of either sex develop to a stage without manifesting any sexual differences but later on, the development in case of the *male* is arrested and it undergoes retrogressive changes. It gets attached to the proboscis of the female, proceeds towards the mouth where it becomes the adult male, finally crawls to the nephridium of the female where it stays for good.

It is extremely interesting that the sexual potentialities in all the larvae of *Bonellia* are similar but only those larvae develop into males which come in contact with the body of the adult female. The intimate contact with females inducing the character of maleness is a highly remarkable and fascinating biological phenomenon.

Class VI. **Sipunculoidea** : marine worm like animals living in natural rock fissures or shells of mussels, in tubes of polychaete worms or amongst corals. Some burrow and make excavations in sand or mud along the sea-coast. The adult shows no trace of segmentation and has no protomium. There is a continuous uninterrupted coelom. Chaetae are completely absent and there are no parapodia. The anterior part of the body can be invaginated into posterior part forming an introvert; anus is dorsal and anterior. There is only one pair of nephridia which act like gonoducts. The larva is a modified *trochophore.*

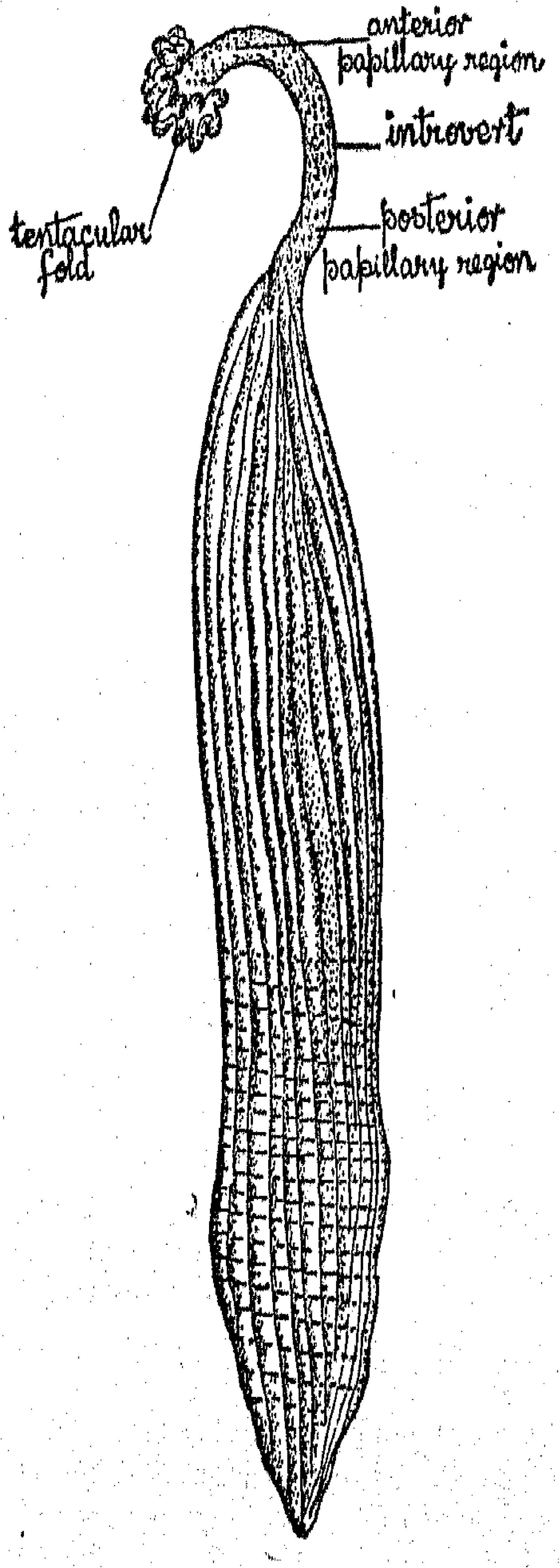

Fig. 226. Sipunculus sp.

Sipunculus is an unsegmented cylindrical elongated worm showing no trace of segmentation. The anterior part forms the *introvert* covered over by papillae. At the free end of the everted introvert is a horse-shoe shaped fold of integument, the *tentacular fold.* The posterior region of the body is devoid of papillae but has longitudinal marks or line-like impressions. A cuticle covers the body. The coelom is spacious and continuous. The blood system is weakly developed. The anus is on the dorsal side in the anterior region, the two limbs of the gut are spirally twisted round one another. A narrow groove runs lengthwise in the alimentary canal except in the rectum. There is a small *bilobed cerebral ganglion* with two *oesophageal connectives* and a double *nonganglionated nerve cord.* There is a single pair of nephridia and the nephridiopores lie a little in front of the anus: they open into coelom internally. The nephridia act as gonoducts and through them the sex cells floating in the coelomic fluid pass out. Sex cells are formed only in a particular season and no definite gonads are found.

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Characteristics of the Phylum Arthropoda

The members of the phylum Arthropoda possess the following characteristics :—

(1) Perfect bilateral symmetry (2) truly metamerically segmented body (3) paired *jointed appendages* on some or all of the segments of which at least one pair function as jaws (4) a stout chitinous cuticle invests the body which is flexible at places in the trunk and limbs forming movable joints at intervals ; the chitin forms a protective exoskeleton (5) the mouth and the anus lie at opposite ends of the elongated body (6) the central nervous system is of the annelidan pattern and consists of a dorsal brain and a double ventral chain of ganglia (7) the coelom in the adult is much reduced and largely replaced by a *haemocoele* with communicates with the circulatory system and is in fact developed from it ; (8) true nephridia are wanting ; one or more pairs of coelomoducts function as genital ducts and often as organs of excretion (9) the muscles are always striped and (10) cilia are not found (except in *Peripatus*) in any part at any stage.

The phylum Arthropoda (*Gr. arthron*, joint and *podos*, a foot) includes five main classes which have living representatives : I **Onychophora**—*Peripatus* II **Crustacea**—Crayfishes, Crabs, Shrimps, Wood lice, Barnacles, Water fleas etc. III **Myriapoda** —centipedes and Millipedes IV **Insecta**—cockroach, locust, flies, butterflies, bees, mosquito etc. V **Arachnida**—spiders, scorpions, mites etc.

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Palaemon A Crustacean

1. **Describe briefly the external characters of** ***Palaemon.***
2. **Give an illustrated account of the appendages of Palaemon and show how their structure has been modified to perform different functions.** (L. U. B Sc. Prel., 1954)
3. **Describe the respiratory organs in** ***Palaemon*** **and point out the adaptations of its respiratory organs.**
4. **Describe the digestive system of** ***Palaemon.*** (L. U. B. Sc. Prel., 1958)

NOTE—*Palaemon* is a swimming freshwater prawn belonging to the order **Decapoda** (hinder five pairs of thoracic appendages are modified as walking legs or swimming organs) under the class **Crustacea.** The **Crustacea** *can be defined as arthropoda with mostly aquatic life and respiration adapted for that life ; the second and third somites bear antennae and the fourth somite has a pair of mandibles. Respiration occurs by gills or the general body surface or the lining of the carapace. In terrestrial forms there may or may not be found special adaptations for breathing air ; the lining of the carapace may be produced into vascular tufts which may be capable of breathing air.*

Ext. characters : elongated spindle shaped body formed of an (i) anterior *unjointed* **Cephalothorax** formed of presegmental region+the first 14 segments (Head+thorax=*cephalothorax* ; presegmental region+embryonic first somites+somites of the first five pairs of appendages=*head* ; succeeding eight segments=thorax), (ii) a posterior *movable jointed* abdomen formed of six segments and (iii) a terminal tail plate or *telson.* A stout cuticular pigmented *exoskeleton* hardened by deposition of lime salts invests the entire body. Each of the six abdominal segments has a hardened exoskeleton piece called *sclerite* ; between the sclerites of successive segments are found thin flexible *arthrodial membranes* due to which sclerites can move in relation to one another. The ring like sclerite of each abdominal segment consists of a convex dorsal tergum which extends downwards on either sides as *pleuron* and a ventral *sternum.* The *telson* is not a segment but forms the post segmental region of the body.

The *mouth* lies between the 3rd and 4th segments of the head. The segments of the **head** (embryonic first somite and the somites of the first five pair of appendages) are all fused and hence their terga together form a *dorsal plate*; in front the carapace[1] is continuous with the dorsal plate; the dorsal plate of the head together with the carapace forms the dorsal shield. The dorsal

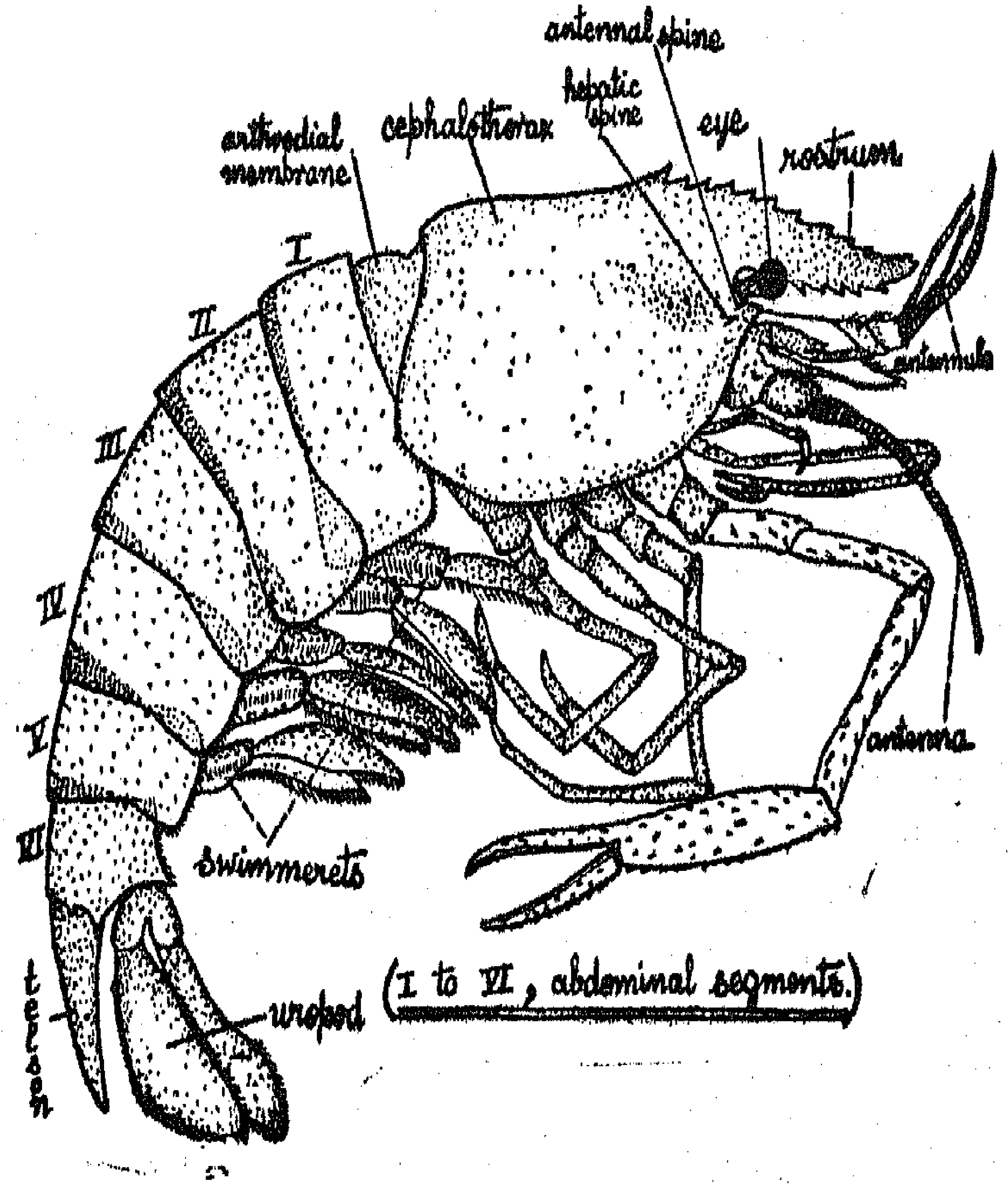

Fig. 227. Lateral view of Palaemon.

plate of the head is produced anteriorly into a median *rostrum* at the base of which elevated on movable stalks are found a pair of *eyes.* The *carapace* is fused in the middle line with the terga of all the thoracic segments but *is free* on the lateral sides in which region it hangs downwards on either side of the thorax as a convex plate known as the *branchiostegite* or *gill-cover*; the *gill-chamber* is the spacious cavity between the thoracic wall and the gill cover.

The slit-like ventrally situated mouth is bounded in front by the *labrum* or *upper-lip*, behind by a *metastoma* (lower lip) and on the sides by the *mandibles.* The anus lies on a minute elevation on the ventral surface of the telson; the paired renal apertures are located on papillae on the inner surfaces of the antennae. Each of the two *male genital apertures* is present on a papillae on the inner surface of the base of the last pair of walking legs. In the female, the *female genital* apertures are found on the inner side of the base of the 3rd pair of walking legs. On the basal segment of each antennule is found a depression at the proximal end of

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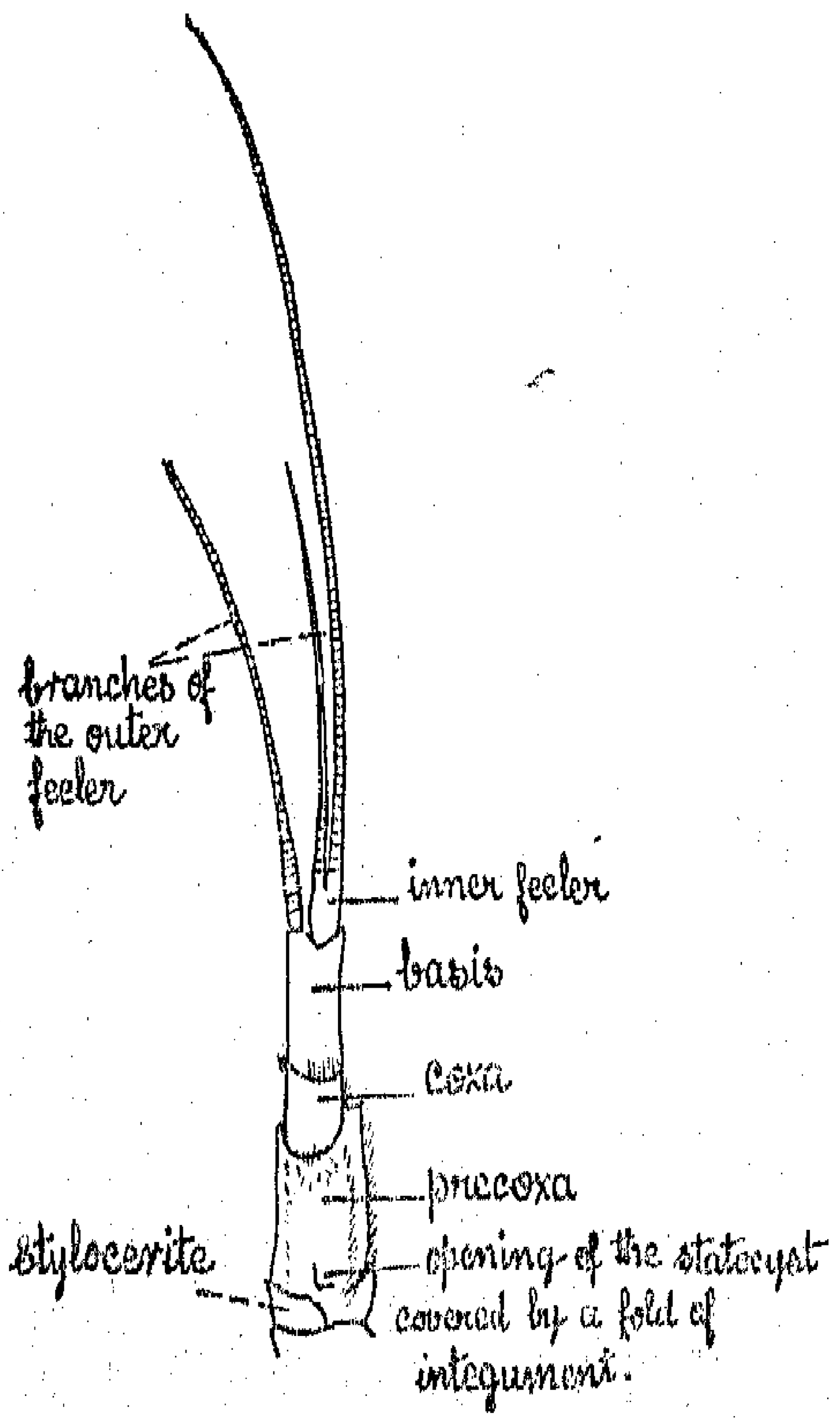
[1] *Carapace* is the dorsal fold of skin arising from the hinder border of the head and extends to a certain extent over the trunk.]

which is found the *opening of statocyst*; each of this pair of openings lies beneath a fold of integument.

The Appendages

Stenopodium is the term applied for the fundamental type of slender biramous appendage i. e. the appendage which forks distally into two rami: an inner *endopodite* and an outer *expodite*, both of which are held upon a common stom, the *protopodite.* The appendages borne on the various segments of the prawn have the basic pattern of a stenopodium. This fundamental type of appendage (stenopodium) has undergone various modifications in relation to the functions discharged by it and as a result in the adult the various appendages appear to differ widely from one another both structurally and functionally.

The **cephalothorax** bears 13 pairs (5 pairs of cephalic and 8 pairs of thoracic) and the **abdomen** bears 6 pairs of appendages; thus **in all there are 19 pairs of appendages.** The **five pairs of cephalic appendages** from in front backwards are a pair each of: *antennules, antennae, mandibles, maxillulae* and *maxillae*; the **eight pairs of thoracic appendages** are a pair each of *first maxillipedes, second maxillipedes, third maxillipedes* and *five pairs* of walking legs; the **six pairs of abdominal appendages are** the *five pairs* of swimmers and a pair of *uropods* or the tail-feet which along with the telson form a powerful *tail-fin.*


branches of the outer feeler
inner feeler
basis
coxa
precoxa
stylocerite
opening of the statocyst covered by a fold of integument.

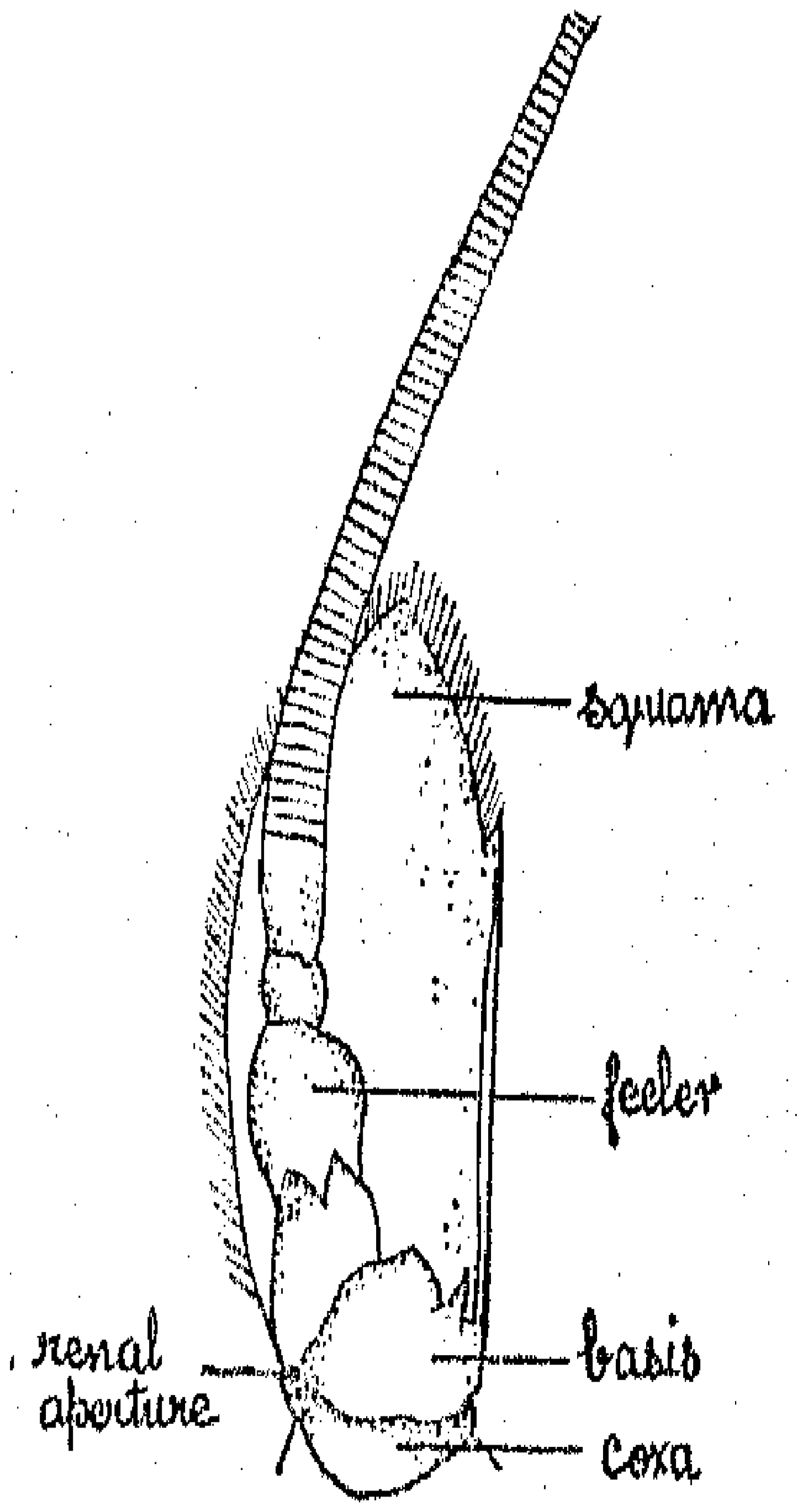


Fig. 229. Antenna, ventral view (The second cephalic appendage).

Fig. 228. The Antennule (Read 'outer feeler' for the above label 'inner feeler'; the single feeler on the left of the diagram is the inner feeler, the error is regretted)

Now we will describe the structure and function of the appendages:

I CEPHALOTHORACIC APPENDAGES (13 pairs)

(a) Five pairs of cephalic appendages: 1 to 5; + (b) eight pairs of thoracic appendages 6 to 13;

(a) *Cephalic appendages:*

1. **Antennules:** Pre-oral, situated immediately below the bases of the eye-stalks; its protopodite consists of *three podomeres*: a large proximal *precoxa*, a short *coxa* and a *basis* which bears two long many jointed feelers, the outer feeler is divided into two *unequal branches*, the *smaller* one bears the olfactory setae. Setae are found on precoxa, coxa and the base of the feelers. *The antennules are olfactory receptor organs.* (At the proximal end of the precoxa, covered over by a fold of integument is found the opening of the statocyst).

2. **Antennae:** situated just behind the antennules, also bear a feeler; the protopodite is made up of a small *coxa* which bears the renal opening on its inner margin and a triangular *basis* bearing the many jointed feeler. The three basal podomeres of the feeler are very large. The coxa and the basis together form the *protopodite*. The basis bears two rami: one is the *feeler* and the other is the broad leaf like *squama* or *scale* which acts as a balancer in swimming. The inner and distal margins of squama are fringed with *tactile* setae. *The aetennae are primarily receptor organs and also act as balancers in swimming.*

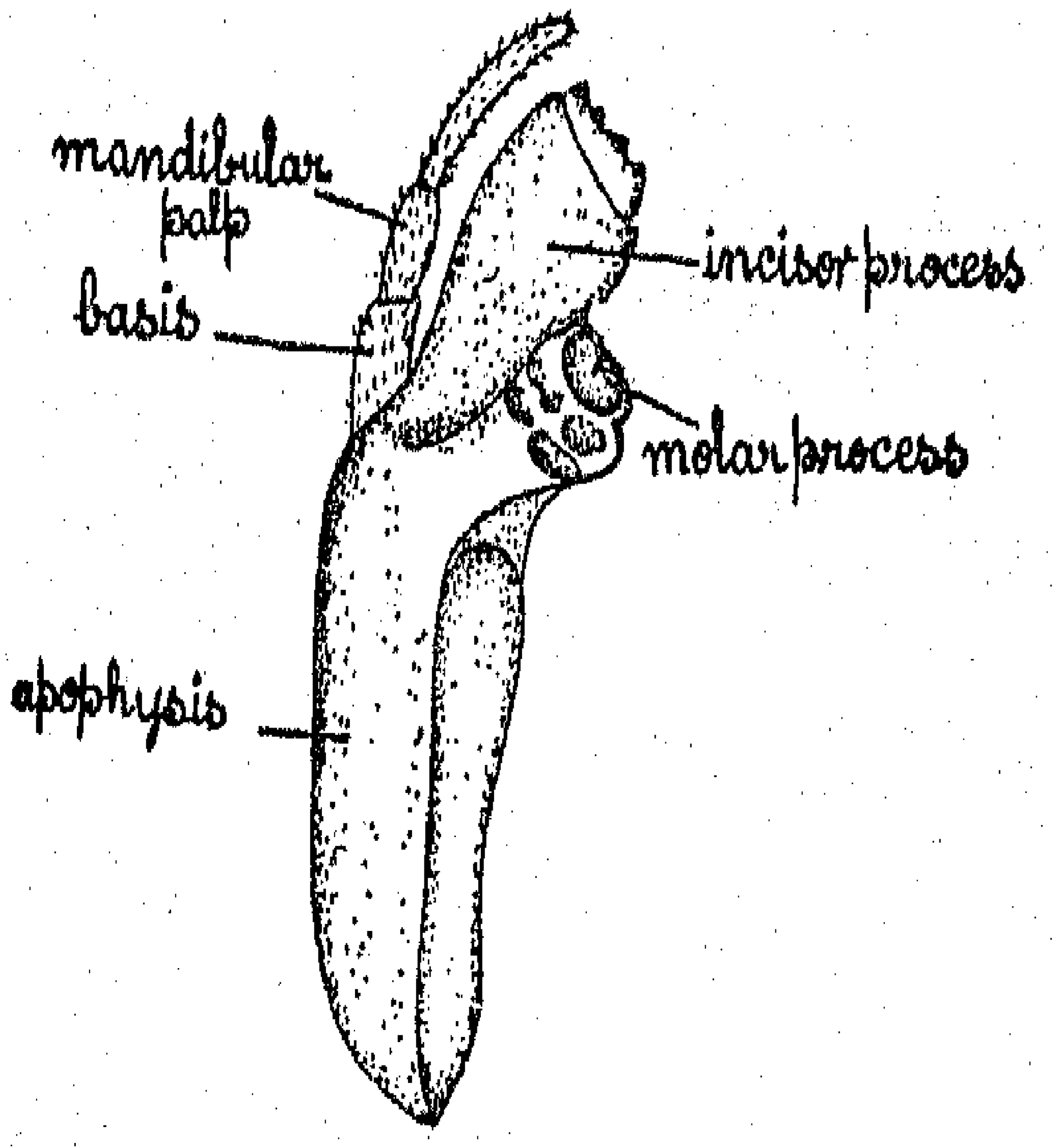


Fig. 230. The Mandible, 3rd. cephalic appendage.

3. **Mandibles** are found one on each side of the mouth; the *coxa* is heavily calcified and forms a powerful jaw of which the spoon shaped proximal portion is the *apophysis* and the solid distal portion is known as the *head*. The *head* consists of a stout *molar process* bearing 5 to 6 dental plates and a flat *incisor process* terminating anteriorly in three closely set *teeth* which lie immediately in front of the oral aperture. A *three-jointed mandibular palp* (bearing setae) is present of which the proximal segment represents the *basis* and the two distal segments represent the endopodite. The exopodite is absent. *The function of mandible is mastication (chewing) of food.*

4. **Maxillulae** are found just behind the lower lip, one on each side; have *no exopodite*; the *protopodite* consists of a *coxa* and a *basis*. The *coxa* and the *basis* project inwards as jaws (gnathobases). From the outer side of the *basis* arises the *endopodite* forming at the distal end a curved bifurcated process. The entire maxillula is thin and foliaceous and the coxa and the basis are beset with pointed spines and setae. *The maxillulae pass food to the mouth.*

5. The **maxillae** have a very small coxa; the *basis* forms a forked *gnathobase* and bears pointed setae at its inner end. The *endopodite* is small but the exopodite forms the fan shaped *scaphognathite* which creates the respiratory current. *Its function is both feeding and respiratory.*

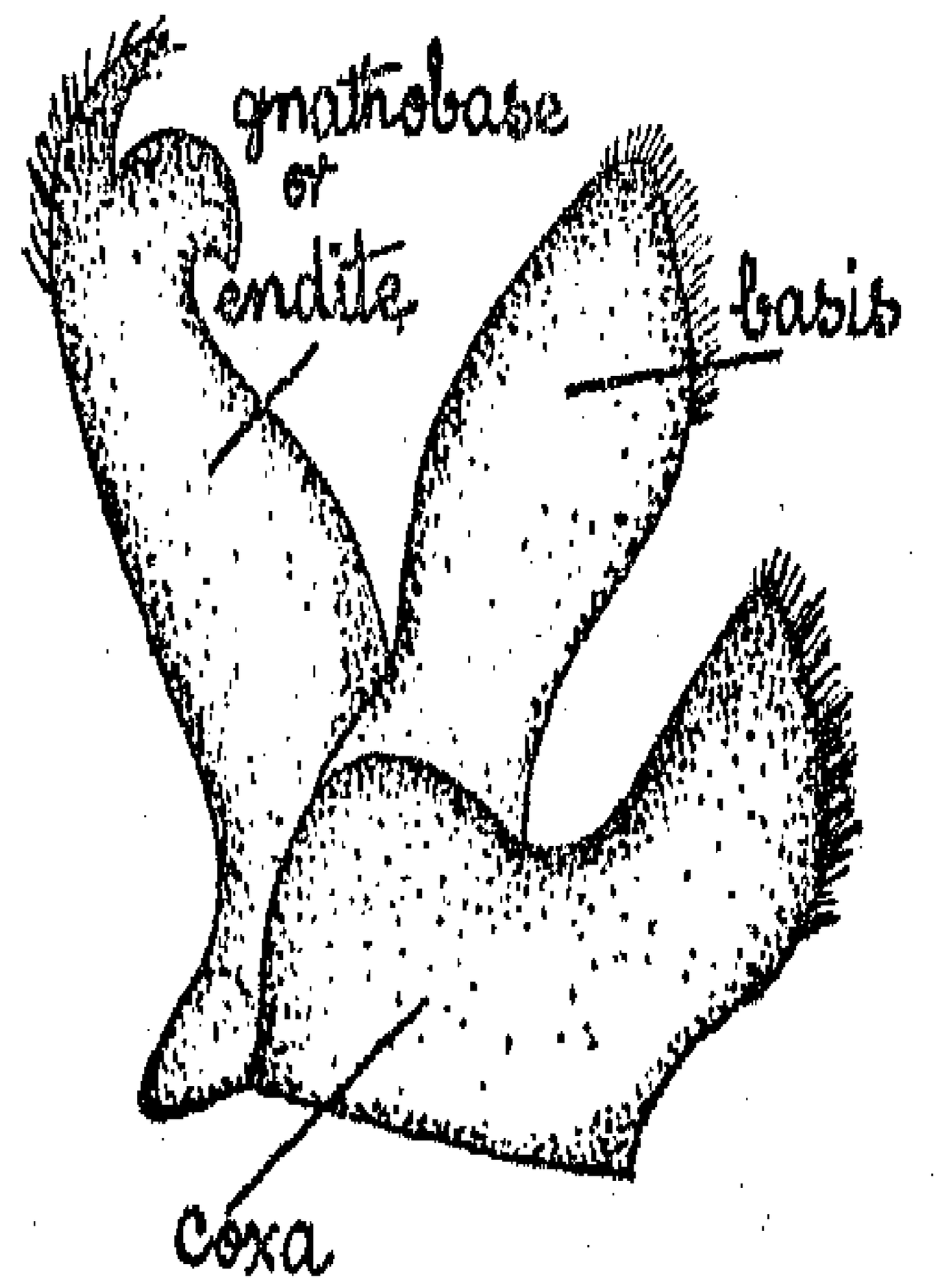


Fig. 231. Left maxillula of Palaemon.

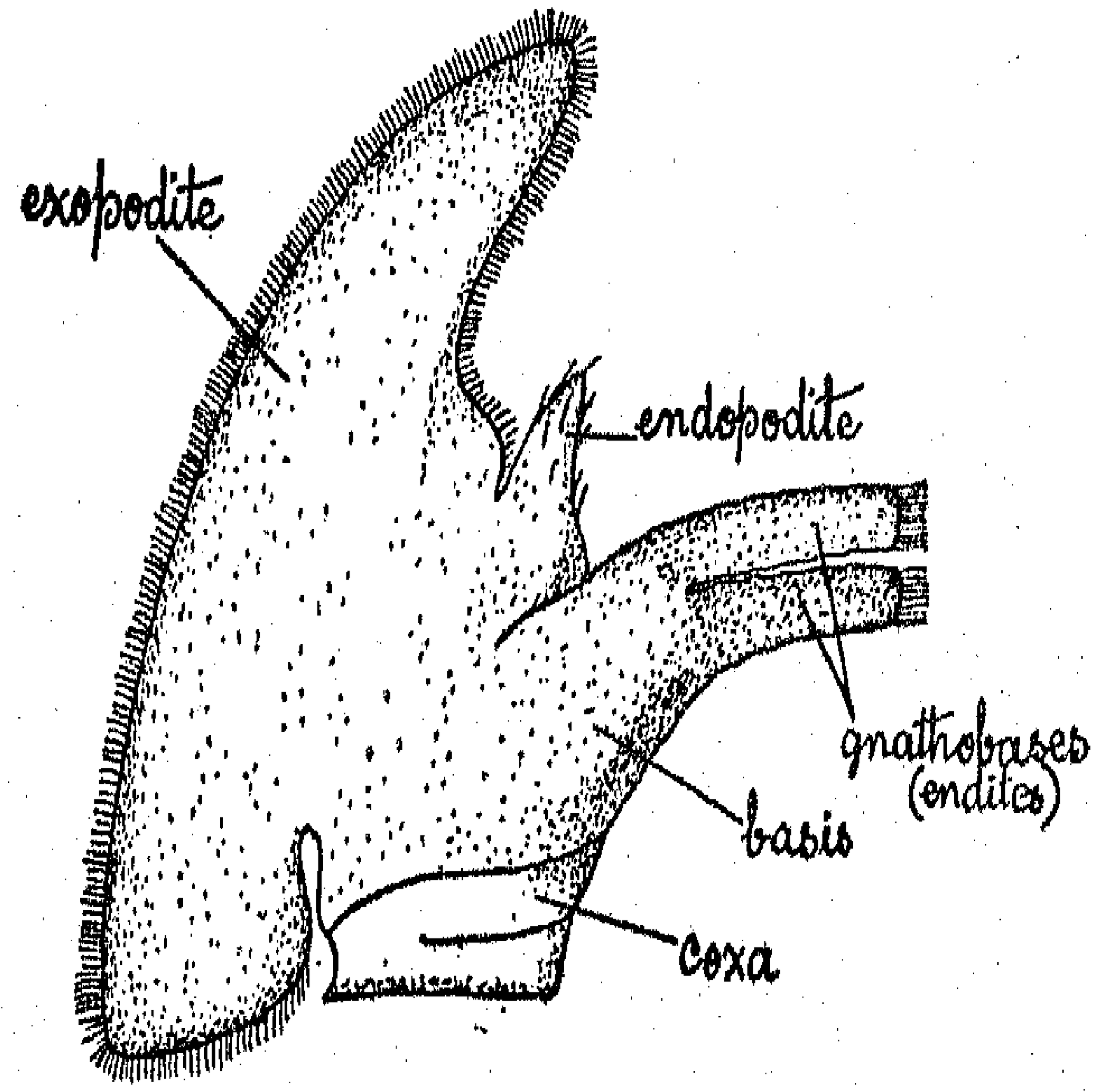


Fig. 232. Left Maxilla (the last cephalic appendage: note the large fan shaped exopodite called the scaphognathite which projects into the respiratory chamber and by its movements maintains a current of water circulating over the gills and hence called a 'baler'.

(b) *Thoracic appendages.*

6. The **first maxillipede:** the coxa and the basis are flattened and project inwards forming two gnathobases bearing two rows of setae. The coxa bears on its outer side a bilobed epipodite of respiratory function. Both the endopodite and the exopodite are unjointed. The *epipodites are respiratory in function.*

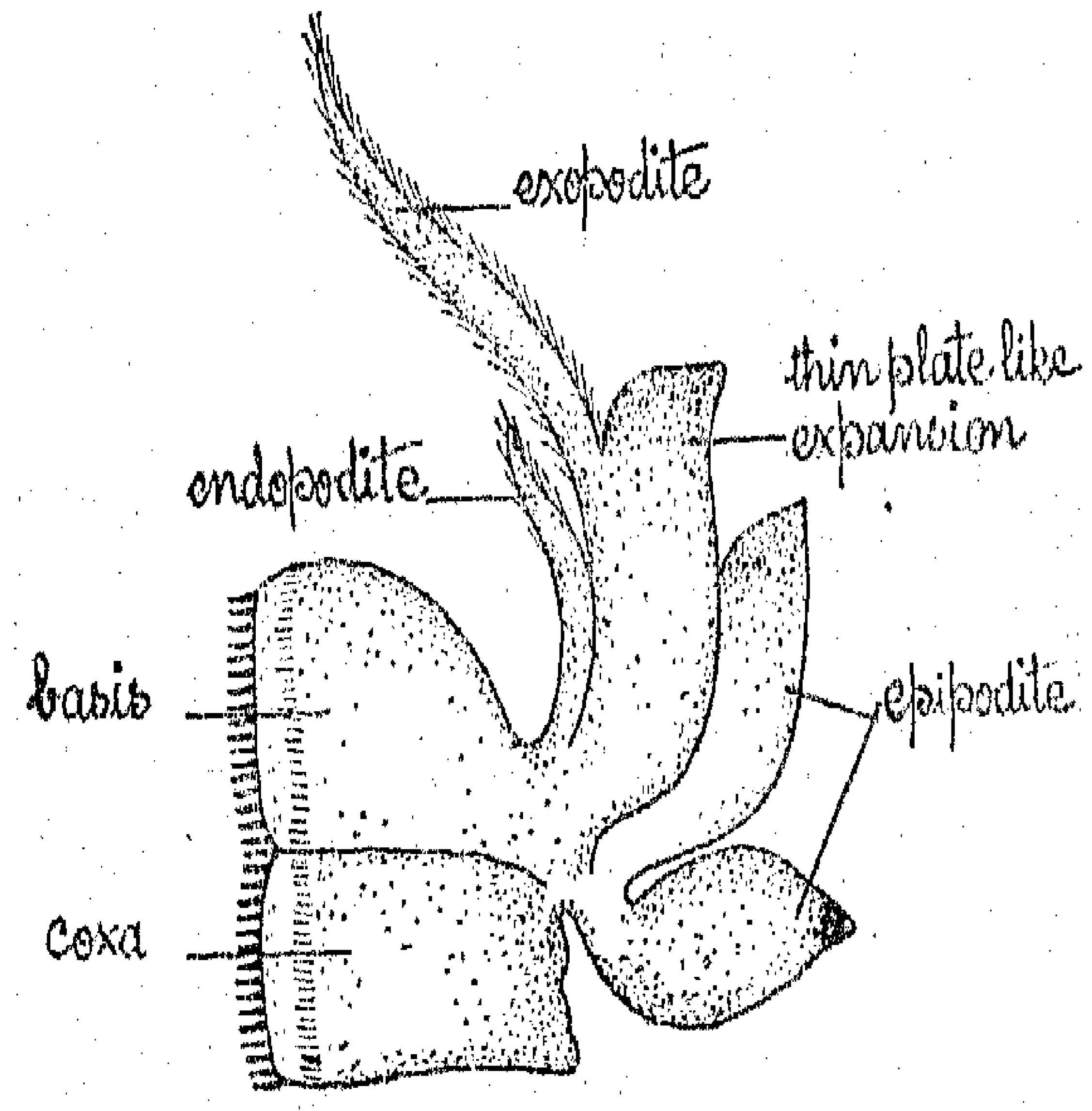


Fig. 233. The first maxillipede of Palaemon (The 1st thoracic appendage).

7. The **second maxillipede:** the short coxa bears an *epipodite* and a *gill* on its outer border; the *basis* is short. The *endopodite* consists of five podomeres (joints or segments): *ischium, merus, carpus, propodus* and *dactylus,* the last two are strongly bent inwards. The dactylus bears pointed spines and forms a stout cutting plate. The unjointed slender exopodite is fringed with setae along its distal half. The *appendage is respiratory in function.*

8. The **third maxillipedes:** are leg like; the coxa bears an epipodite on its outer side; the basis supports *endopodite* and an *exopodite,* the *latter* is unjointed and thickly covered with setae. The endopodite is made up of three podomeres: (ischium + merus), (carpus) and (propodus+dactylus).

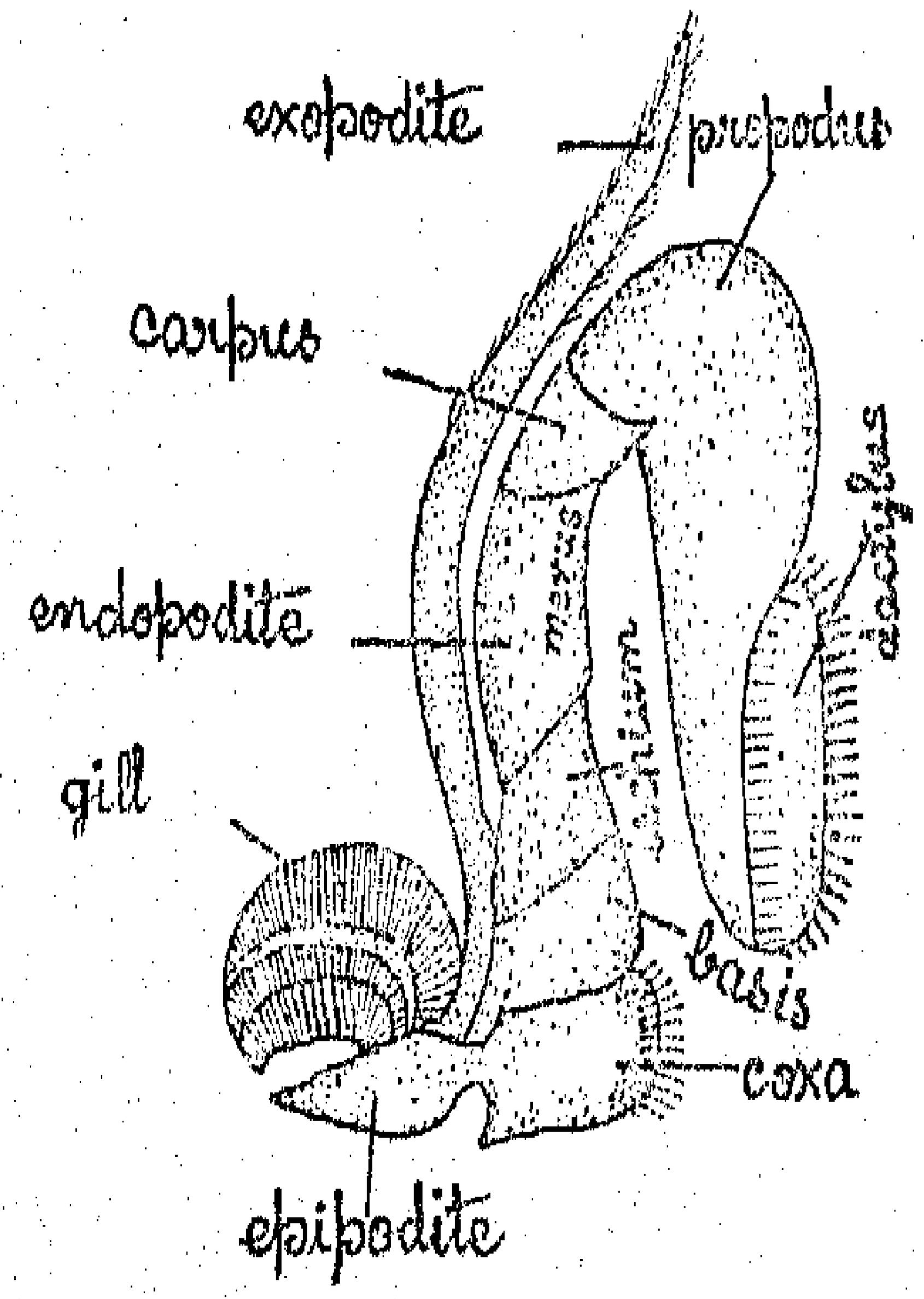


Fig. 234. The second maxillipede of Palaemon (The 2nd. thoracic appendage).

The 9th., 10th., 11th., 12th., and 13th., are the five pairs of **walking legs** in all of which the exopodite is absent and no epipodite is developed. The entire leg consists of the *protopodite* (*coxa* and *basis*) and the *endopodite* (*ischium, merus, carpus, propodus and dactylus*). The dactylus is clawed.

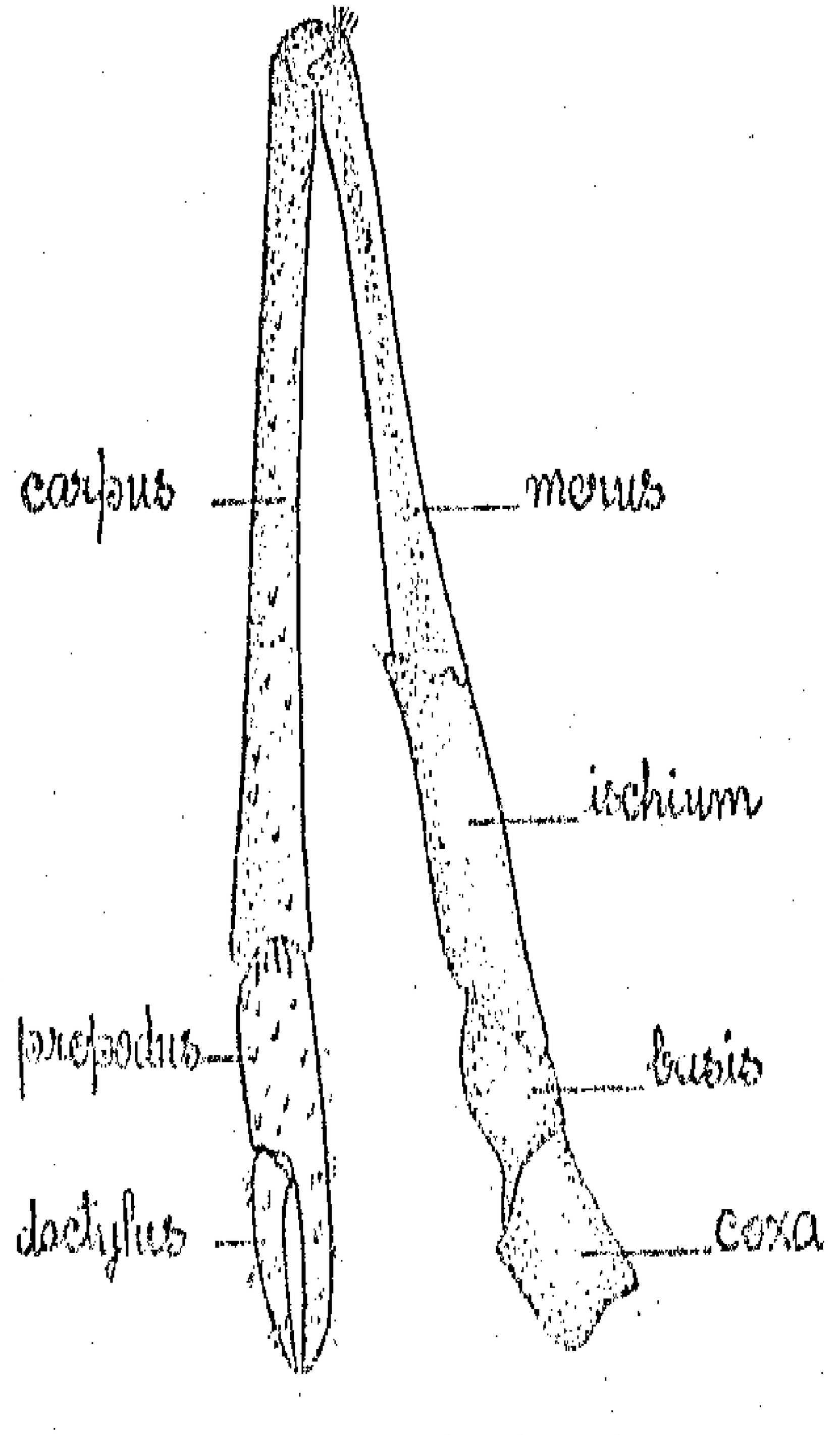


Fig. 235. First walking leg of Palaemon [9th. appendage] The leg is chelate.

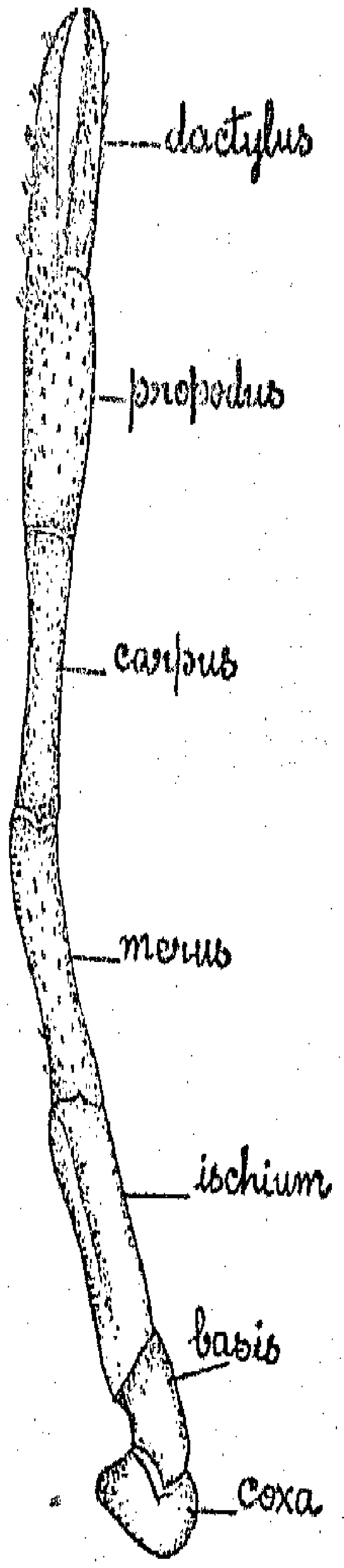


Fig. 236. Second chelate leg of the male prawn. [Note that these are longer and covered with more spines and setae than in females].

The **first** and the **second pair of walking legs** bear forcep like **chelae** terminally. The chela is formed by the propodus and the *dactylus,* the *latter* remains movable against the propodus. The propodus and the dactylus bear teeth in the region where they oppose each other. The chelate legs are of use in the capture of prey and its transport to the mouth. The second chelate leg is larger in size and stouter than the first and is used for offence and defence in addition to the capture of prey.

The 3rd., 4th. and 5th. pairs of walking legs do not bear chelae. On the inner side of the coxa of the 3rd pair of walking legs (in females) is found the female genital apperture. The male genital aperture is found on the inner side of the arthrodial membrane connecting the 5th. pair of legs to the thorax. *All the five pairs of legs are used for walking slowly on the bottom.*

II ABDOMINAL APPENDAGES

The **abdominal appendages** are six pairs and are biramous; they are known as *pleopods* or *swimmerets.* The sixth pair of these are known as *uropods* or *tail-feet*. A typical swimmeret say the 3rd. abd. appendage has a *protopodite* consisting of two podomeres; a short proximal *coxa* and a long cylindrical distal *basis*. On the outer surface of *basis* are found a number of elongated setae. The *basis* bears an outer large *exopodite* and an inner smaller *endopodite*; the exopodite as well the endopodite are leaf-like and bear setae along their margins. The *endopodite* bears on its inner side a short slender process, the *appendix interna* with a knob-like distal end. In the **first abdominal appendage** the endopodite is small and the appendix interna is absent. In case of male, the appendix interna of the second abdominal appendage bears a special rod-shaped process known as the *appendix masculina*, which is covered over with long setae.

In the **sixth abdominal appendage** (uropods), the coxa and the basis are fused so that the protopodite has a single podomere; both the exopodite and the endopodite are oar-like and bear setae along their margins except along the outer border of the exopodite. Each one of the sixth pair of abdominal appendages is large flat plate-like lying on the side of the telson. The telson along with them forms a *tail-fin*.

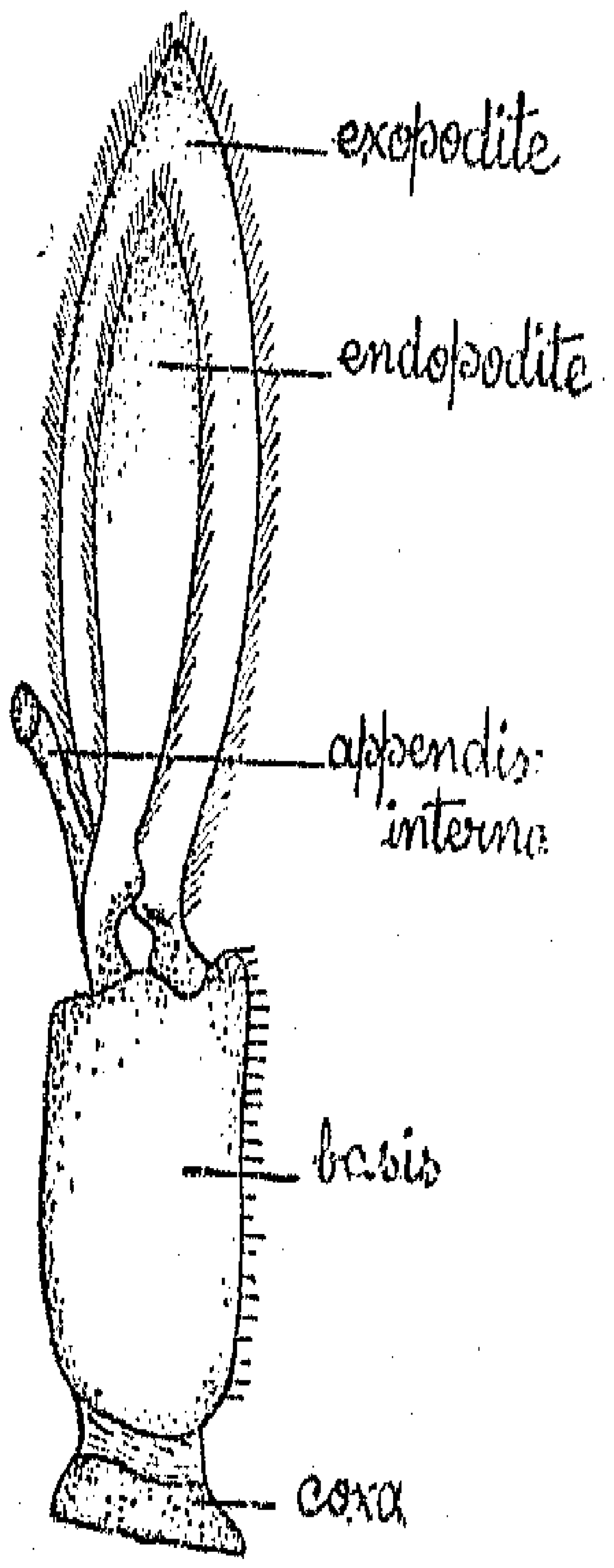


Fig. 237. The third abdominal appendage.

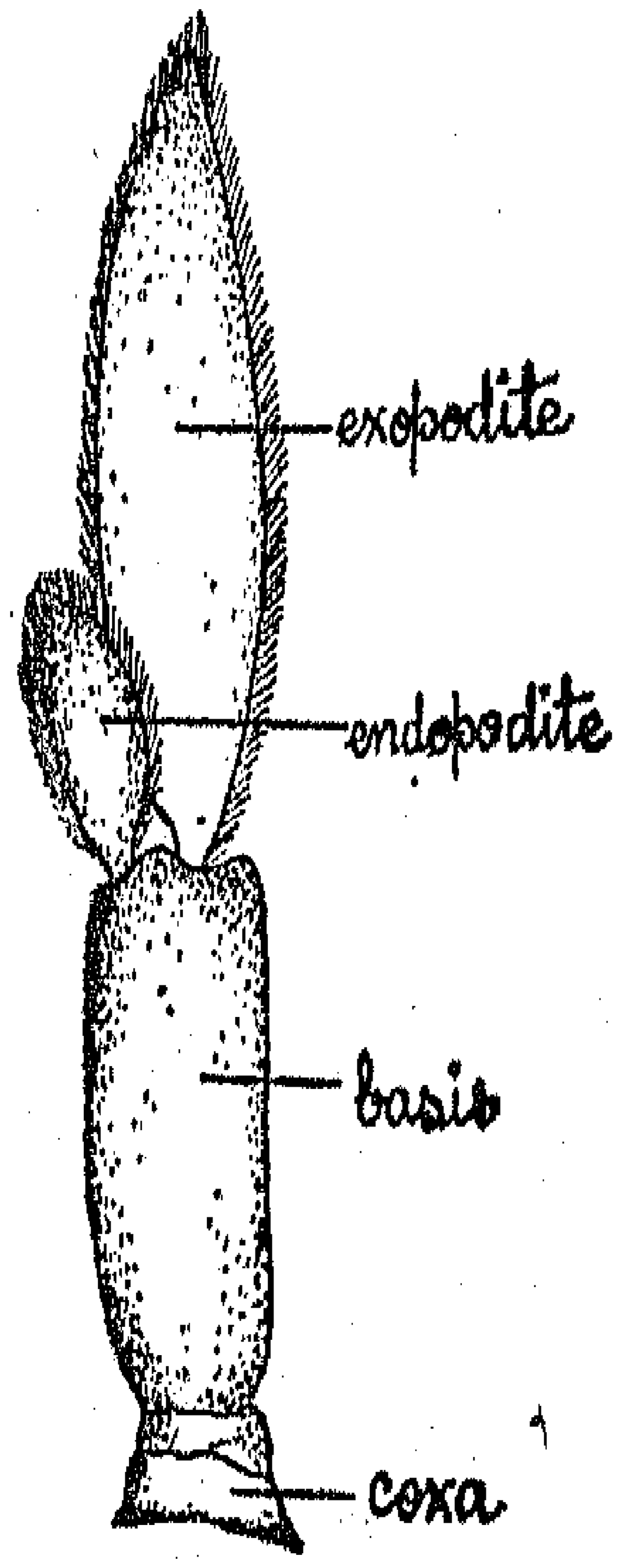


Fig. 238. First abdominal appendage.

The 2nd., 3rd., 4th. and 5th. abdominal appendages in the female carry eggs during the breeding season. The abdominal appendages are also known as *swimmerets* or *pleopods* and they help in swimming.

To sum up, it may be stated that the appendages of *Palaemon* present a wide variety of structure and function. The various functions performed by the different appendages are sensory, mastication, passing of food to the mouth, offence and defence, prehension, respiration, maintenance of a respiratory water current, walking, balance in swimming, actual swimming and that of the tail fin. Due to the flexion of the tail-fin, the prawn can suddenly spring back.

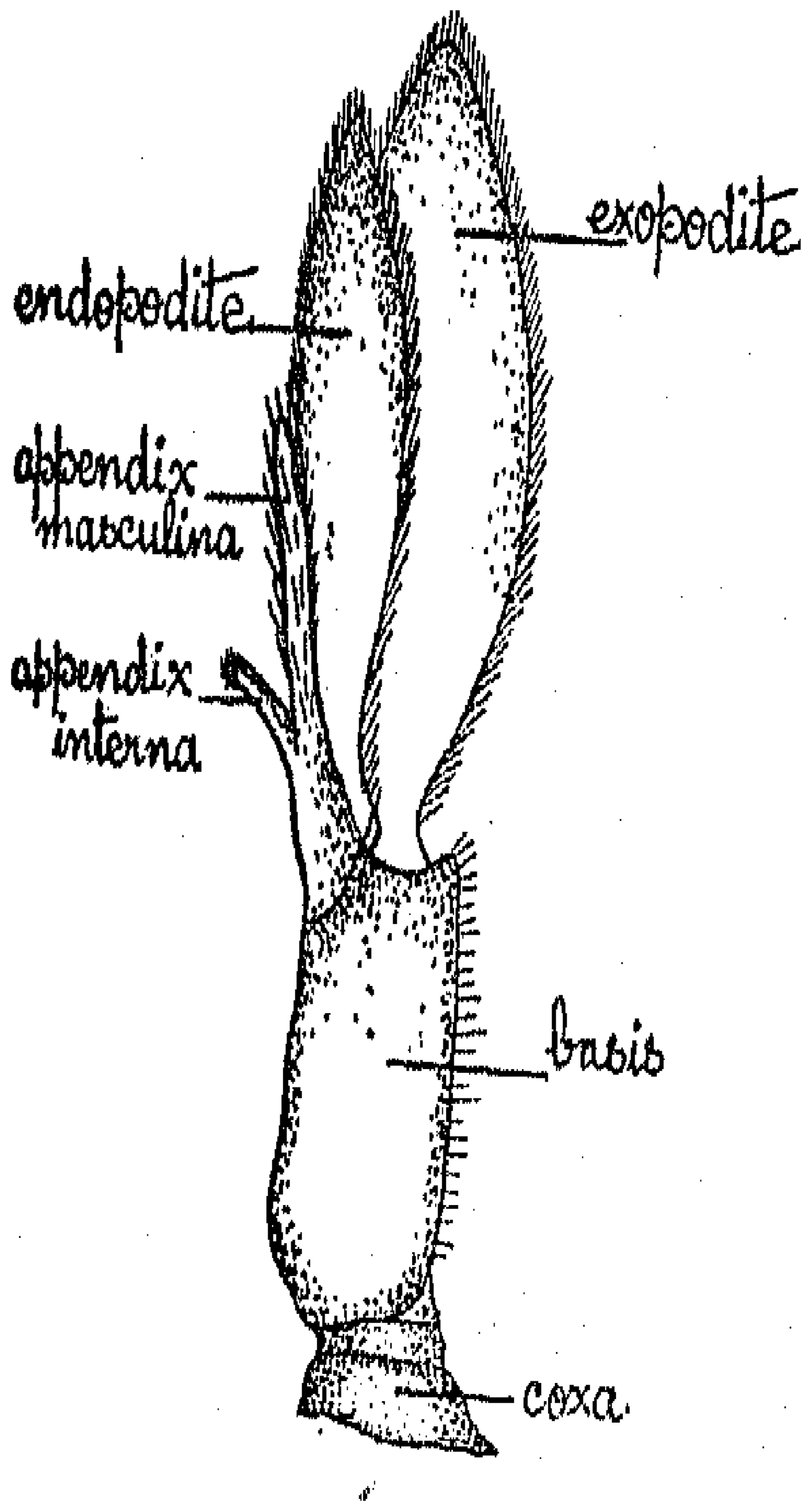


Fig. 239. The second abdominal appendage.

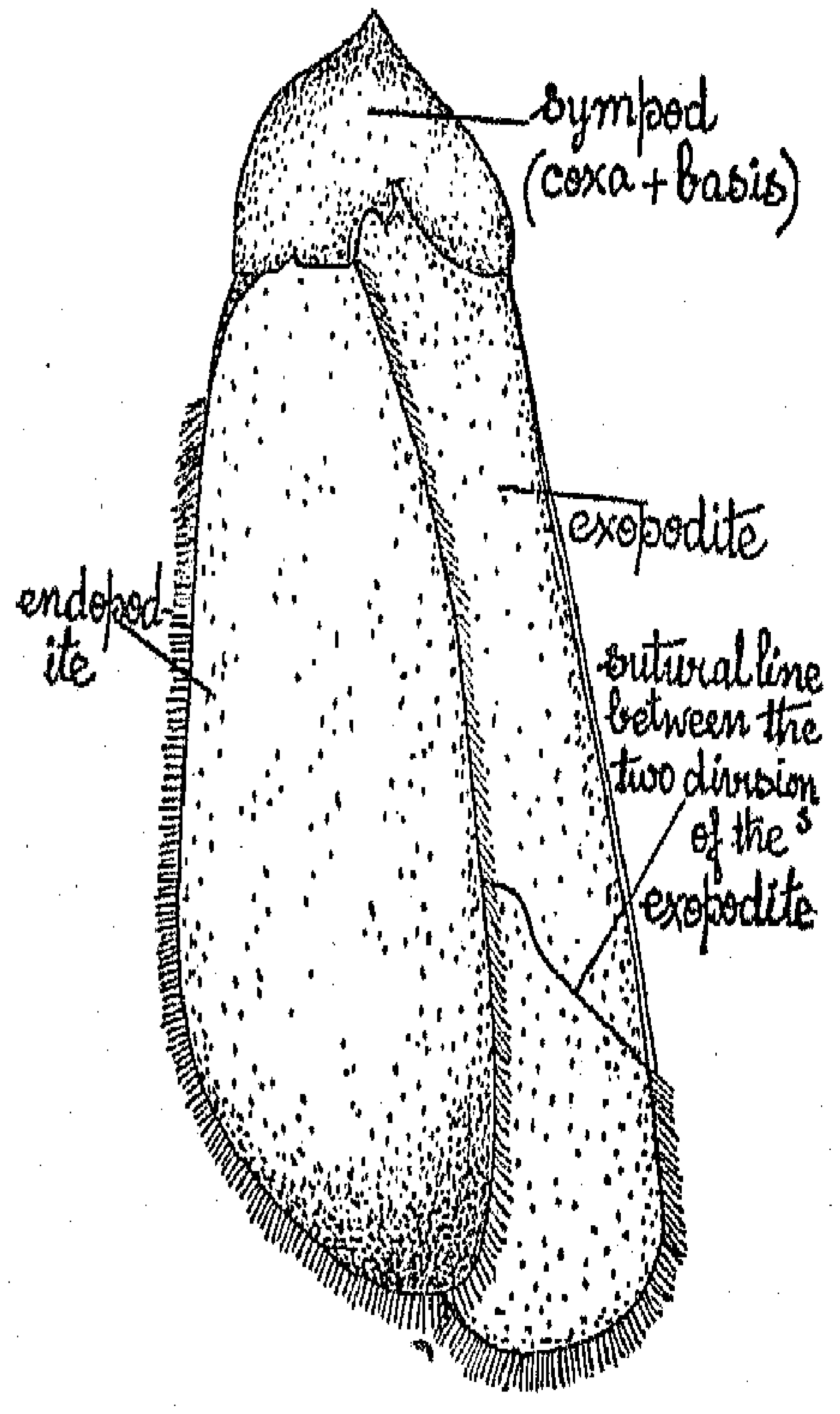


Fig. 240. Uropod or the 6th abdominal appendage.

Respiration

On each side of the thorax is found a *gill-chamber* enclosed between the *gill-cover* (or *branchiostegite*) and the wall of the thorax; the gill-chamber communicates freely with the exterior along the anterior, posterior and ventral sides but is closed on the dorsal side. The gill-chamber of each side accommodates within itself three pairs of **epipodites** and **eight pairs** of **gills** or **branchiae.**

The function of respiration in *Palaemon* is performed by three elements (i) lining of the carapace (ii) three pairs of epipodites and (iii) eight pairs of gills or branchiae.

The thin inner lining of the gill-cover which contains plenty of blood lacunae forms a good surface for the respiratory exchange for which it is constantly bathed in fresh water. The leaf-like *epipodites* (borne by the coxae of the three maxillipedes) lie in the anterior region of the gill-chamber just beneath the 'baler' or *scaphognathite* of the maxilla.

Each gill is attached at about the middle of its length to the thoracic wall ; the place of attachment is called the *root* of the gill; through this root the blood lacunae and nerves enter into and exit from the gill. The eighth gill lies hidden below the second gill.

The **first maxillipede** bears no gill but merely a bilobed *epipodite* on its coxa. The **second maxillipede** bears an *epipodite* as well as a *podobranch*. The **3rd maxillipede** bears *two arthrobranch gills* and an *epipodite*. Gills pertaining to the **five pairs of walking legs** are all pleurobranchs and are attached to the lateral wall of the thorax. Each walking leg bears *one pleurobranch*. [When a gill is attached to the coxa of an appendage, it is known as a *podobranch* ; when the gill is attached to the arthrodial membrane which connects the appendage to the thorax it is called an *arthrobranch* ; when the gill is attached to the lateral wall of the segment to which it pertains, it is known as a pleurobranch.]

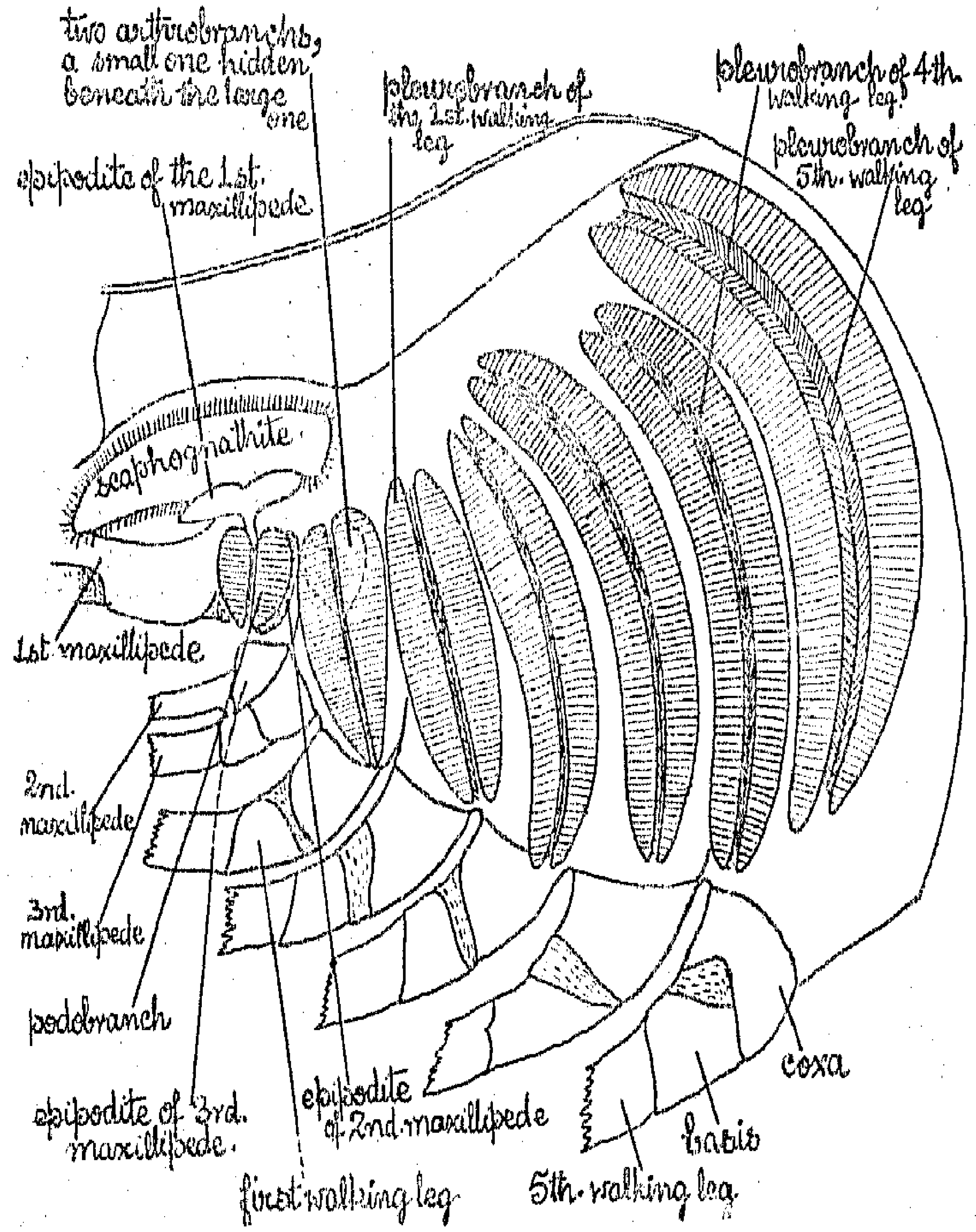

two arthrobranchs, a small one hidden beneath the large one
pleurobranch of the 1st walking leg
pleurobranch of 4th walking leg
pleurobranch of 5th walking leg
epipodite of the 1st maxillipede
scaphognathite
1st maxillipede
2nd maxillipede
3rd maxillipede
podobranch
epipodite of 3rd maxillipede
epipodite of 2nd maxillipede
first walking leg
5th walking leg
coxa
basis

Fig. 241. Left gill chamber exposed by removal of the gill chamber.

The gill of *Palaemon* is a *phyllobranch*, for in it the gill filaments are thin and plate-like and are arranged in two rows on a narrow axis like the pages of a book. Between the two rows of gill plates runs a deep groove which opens into the gill chamber at the dorsal and ventral ends of the gill. The gills have an extremely thin cuticular covering and they are highly vascular so that oxygen dissolved in water diffuses into the blood and carbon dioxide diffuses out from the blood into the water.

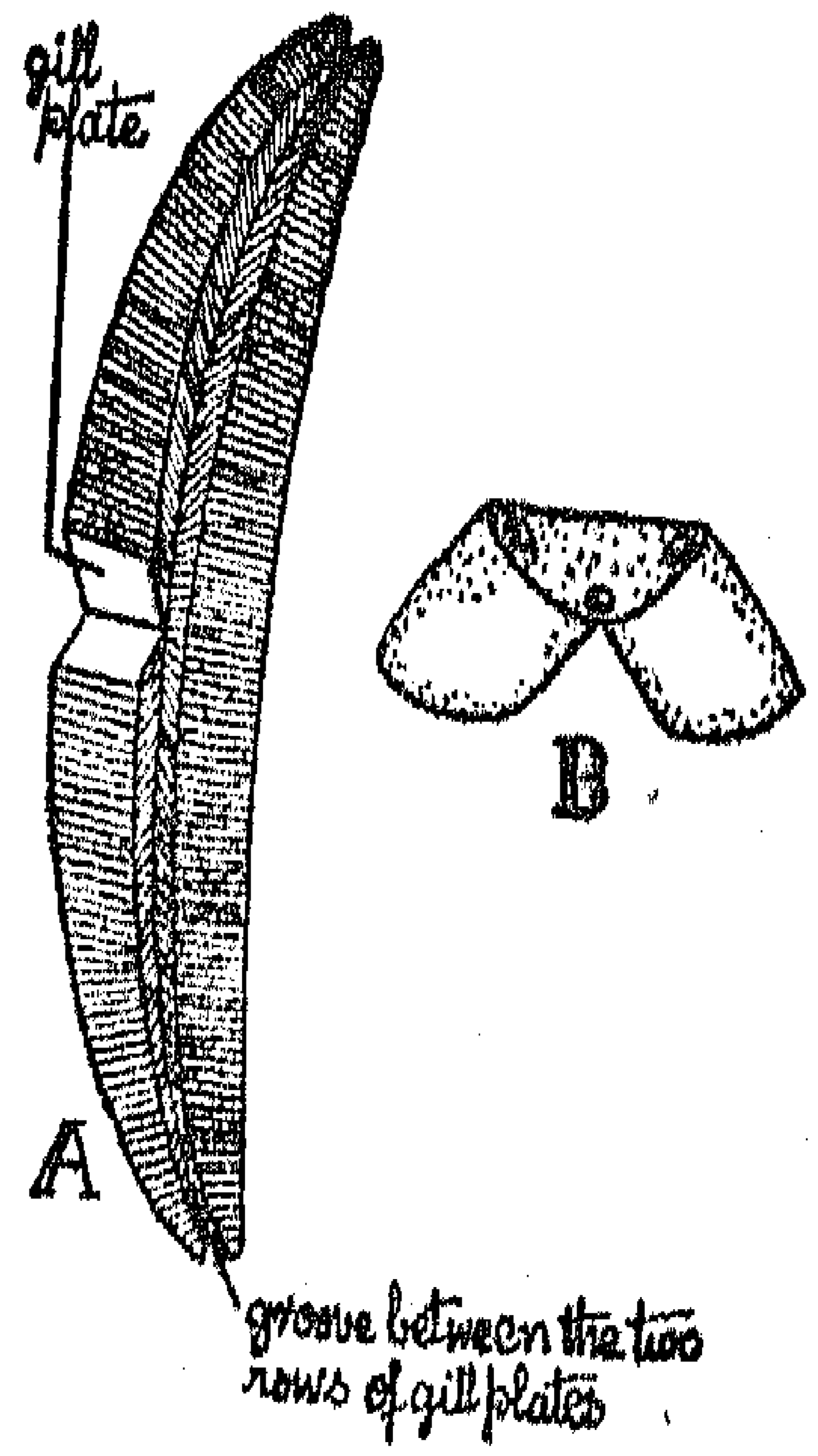


Fig. 242. Phyllobranch of Palaemon ; A shows the complete gill ; B shows transverse section of the same.

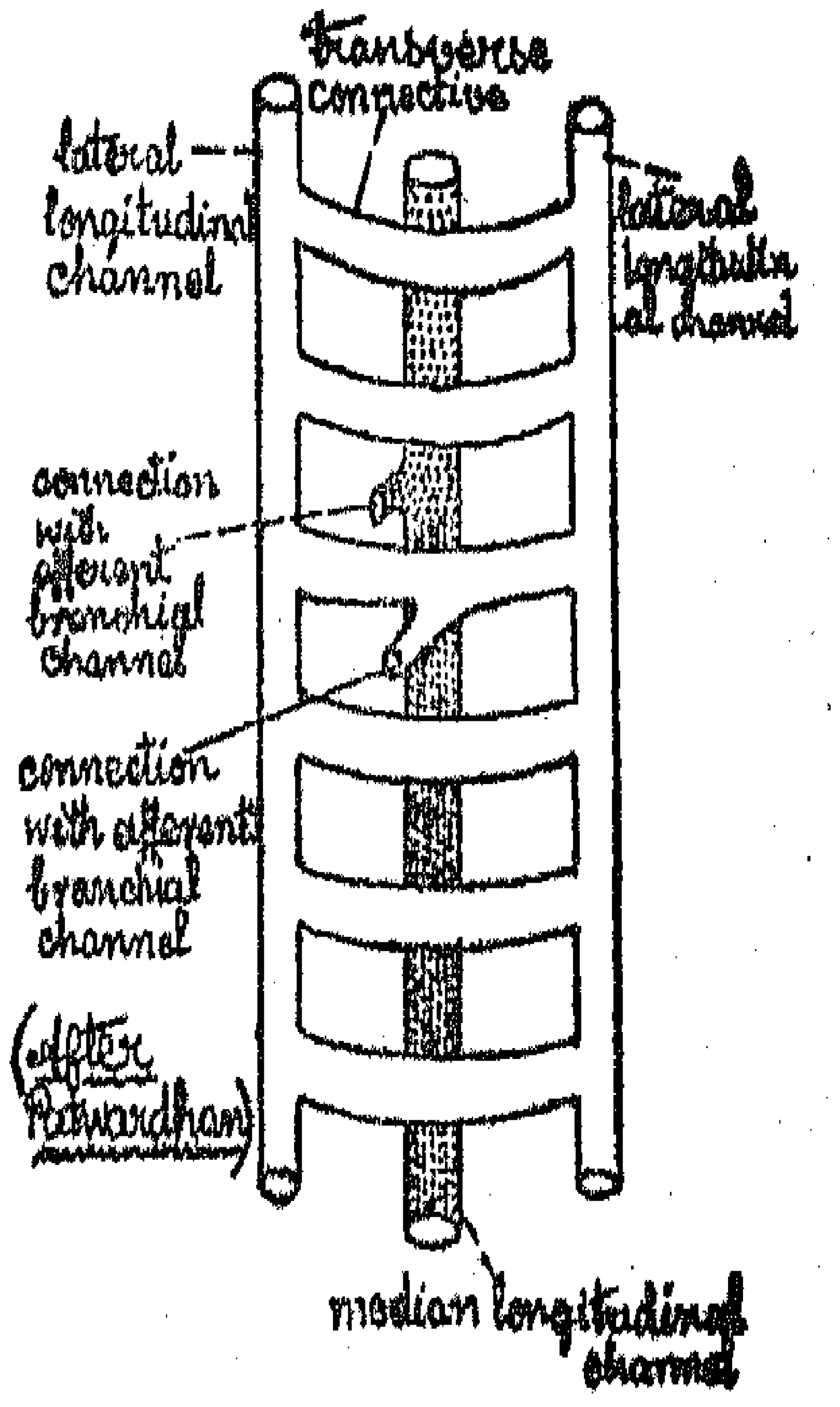

transverse connective
lateral longitudinal channel
lateral longitudinal channel
connection with efferent branchial channel
connection with afferent branchial channel
(after Patwardhan)
median longitudinal channel

Fig. 243. Diagrammatic representation of the blood vessels in a gill.

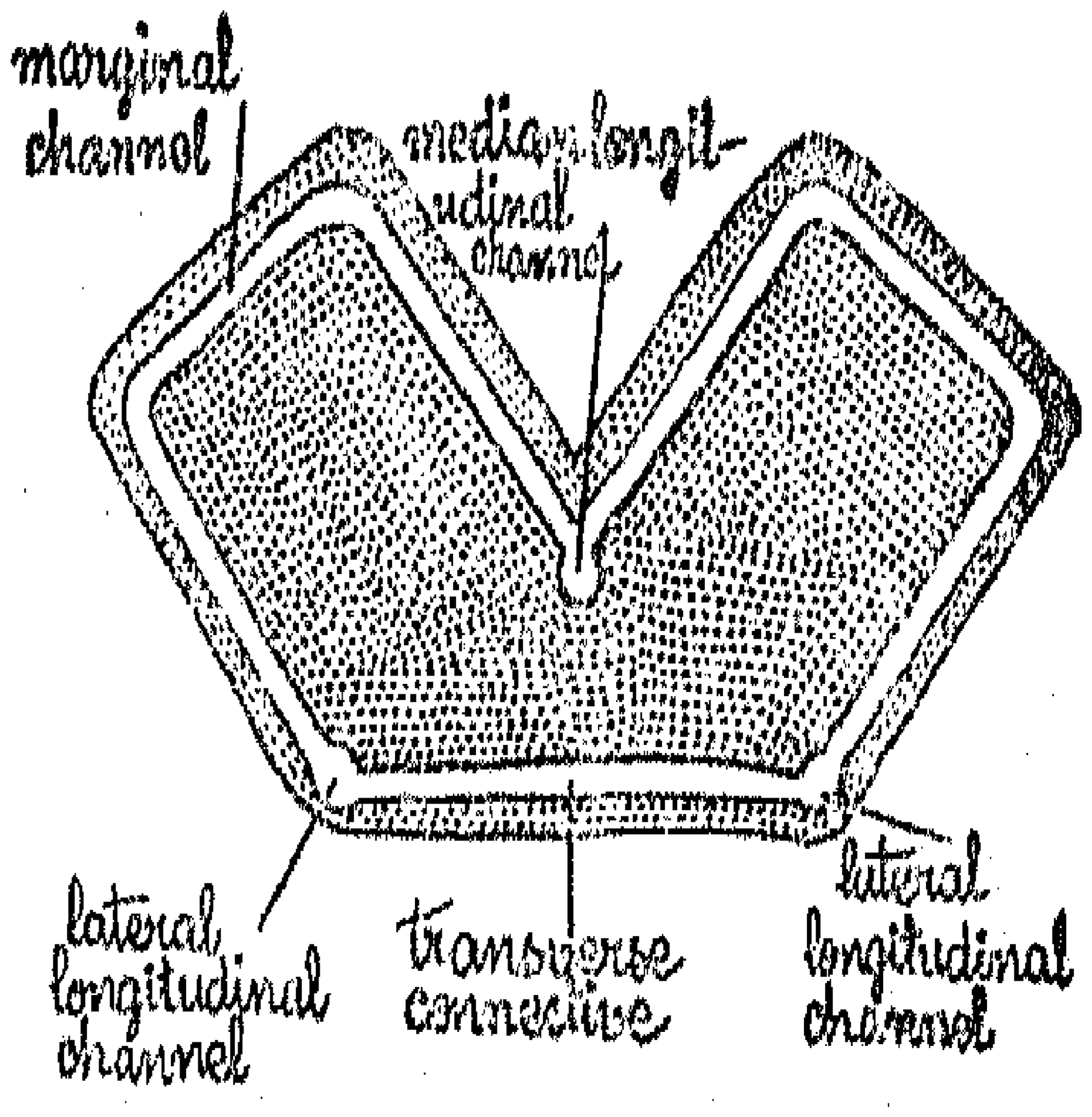

marginal channel
median longitudinal channel
lateral longitudinal channel
transverse connective
lateral longitudinal channel

Fig. 244. Diagrammatic representation of the blood channels in a gill ; transverse section [After Patwardhan].

Three *longitudinal channels* run through the triangular axis of base of each gill, two *lateral longitudinals* along its lateral margins and one *median longitudinal* running just below the groove. The two lateral longitudinals communicate by several *transverse connectives* of which the one that lies just against the root of the gill gets the blood from the body through the afferent branchial channel for aeration. From each lateral longitudinal, a *marginal channel* arises at the place of attachment of each gill plate; it runs along the margin of the gill plate and then opens into the median longitudinal channel which sends the oxygenated blood into the efferent branchial channel and thence to the pericardial sinus and the heart.

The fan-like exopodite (scaphognathite) of the maxilla create a water current (by their vibrating movements) which enters the gill-chamber along the posterior and ventral margins of the gill-cover and passes over the gills. This water is expelled out at the anterior end of the gill-chamber. Thus the gill chamber containing the epipodites and gills and the lining of the carapace are being always bathed in the flowing water.

Adaptations of Respiratory organs in prawn (*Palaemon*)

Palaemon is well adapted to the **aquatic mode of respiration.** The main adaptive respiratory adaptations of the prawn are: (i) presence of the *scaphognathite* (fan-like exopodite) in maxilla which creates the respiratory water-current, (ii) restriction of the respiratory area in the gill-chamber (iii) increase in the respiratory surface due to development of epipodites which become folded and form delicate gills which instead of remaining attached to the precoxa have become attached to the lateral wall of thorax and have been enclosed in the gill-chamber and (iv) the *carapace* forms a protective gill-cover for the delicate gills; *it* forms a definite gill-chamber on each side of the thorax.

Digestive system

The alimentary canal consists of a **fore-gut,** (*mouth, buccal cavity, oesophagus and stomach*), a long slender **mid-gut** and a short **hind-gut** opening by *anus*. The fore gut (*stomodaeum*) and the hind gut (*proctodaeum*) are lined with *cuticle* (intima) continuous with the cuticle of the general body surface.

The *mouth opening* lies on the ventral side of the head and is bounded in front by the *labrum* (upper lip), behind by the *labium* and on the sides by the incisor processes of the mandibles. The labium is cleft in the middle and forms two platelike lobes, the *paragnatha.* The *mouth* leads into the vertical *buccal cavity* into which project from the two sides *molar processes of the mandibles* so that their opposing dental plates are in a position to masticate the food. The buccal cavity leads into a short wide vertical *oesophagus* which has thick muscular walls thrown into four prominent longitudinal folds which project into its lumen. The oesophagus leads into a large *stomach* divisible into a (i) *cardiac stomach* and (ii) a very small *pyloric stomach* which lies beneath the (i) and just behind its floor. Between these two parts occur a number of valves. The passage of food from the cardiac stomach back into the oesophagus is prevented by the three folds of the oesophagus which form a sort of valve. A *circular cuticular plate* covers the anterior wall of the oesophageal opening; a similar *lanceolate* plate is found on the roof of the cardiac stomach in its anterior region.

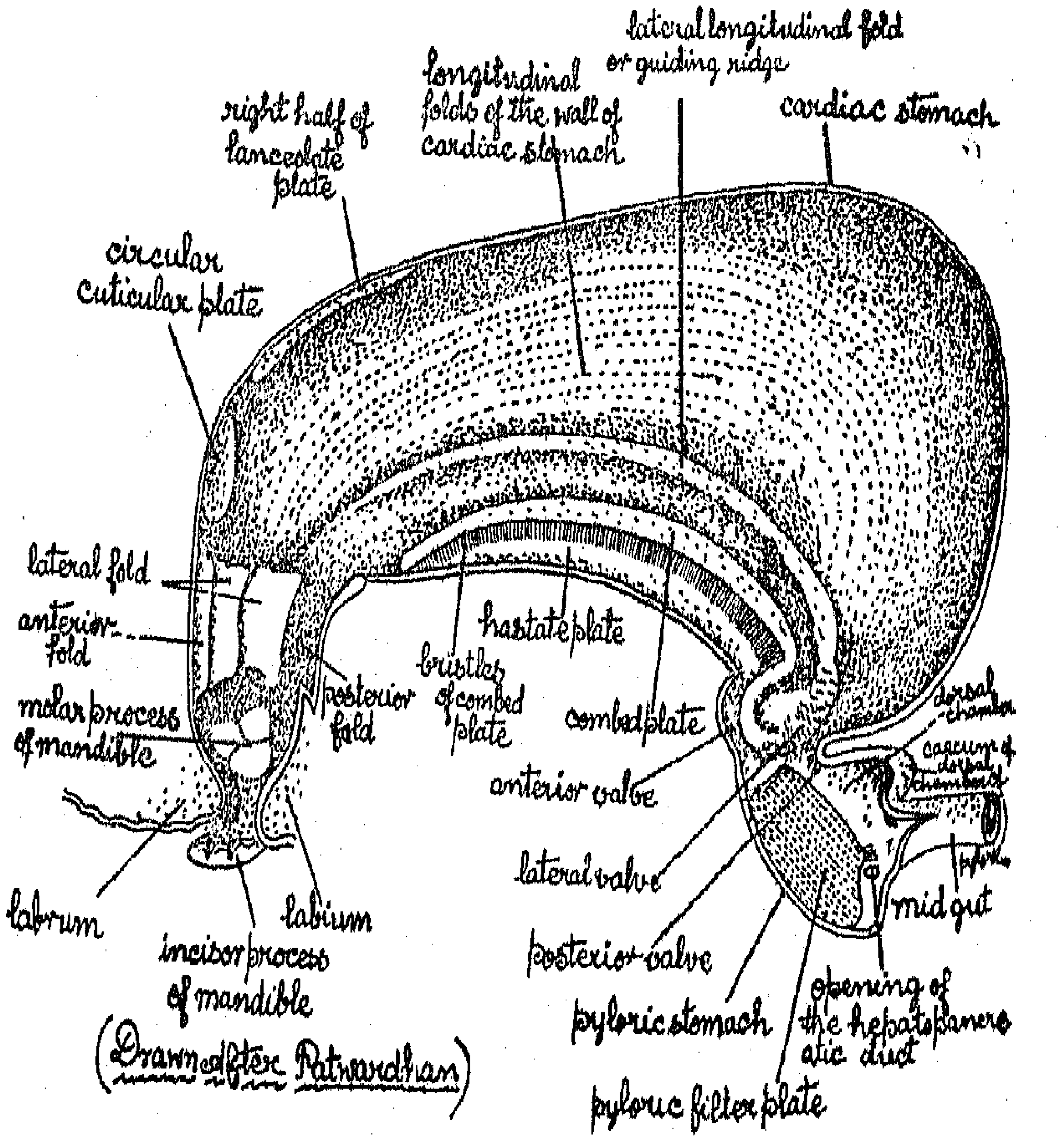


Fig. 245. A semi diagrammatic vertical longitudinal section of the foregut of Palaemon [After Patwardhan].

Inside the cardiac stomach there is an elaborate arrangement for churning and straining the food. The apparatus consists of certain plates, grooves and bristles. A large triangular cuticular plate known as the *hastate plate* lies imbedded in the floor of the cardiac stomach. Its upper surface is covered with a thick growth of fine setae. On the plate there is a median ridge either side of which is sloping towards its outer margin. The posterior border of the plate is thickly fringed with setae forming the *anterior valve* of the *cardiopyloric* aperture. Running parallel to each lateral border of the hastate plate is a long cuticular ridged plate known as the **combed plate.** Each combed plate is separated from the hastate plate only by a narrow *lateral groove.* The outer side of each combed plate forms a broad horizontal plate while the inner side forms a narrow vertical plate, all along its inner border, the ridge of the combed plate is fringed with setae which form a comb like structure covering the groove and also overlapping the outer margin of the hastate plate. The floor of the lateral groove is formed by an open drain pipe like-cuticular *groove plate.* The fine setae of the comb plate keep moving to and fro over the outer margin of the hastate plate. The inner wall of the cardiac stomach is produced into a pair of prominent *lateral longitudinal folds*, one on each side of the two comb-plates. These lateral longitudinal folds have been termed as the *guiding ridges* because they guide the food towards the cardio-pyloric aperture. In *Palaemon*, food is crushed by the molar processes of the two mandibles which project into the buccal cavity and press against each other. In the cardiac stomach a churning and a straining (filtering) action is performed by the bristles of the combed plates which keep moving to and fro over the outer margins of the hastate plate. Due to the moving combs the food becomes finely divided; the liquified food, passing through these combs comes into the lateral groove on each side of the hastate plate. The cardiac stomach constantly expands and contracts so that the food inside is stirred, mixed up with the hepatopancreatic secretion and digested. From the lateral grooves the food passes through the *cardiopyloric aperture* which allows only the finely divided food or the dissolved food, acting like a *sieve* due to thickly set setae.

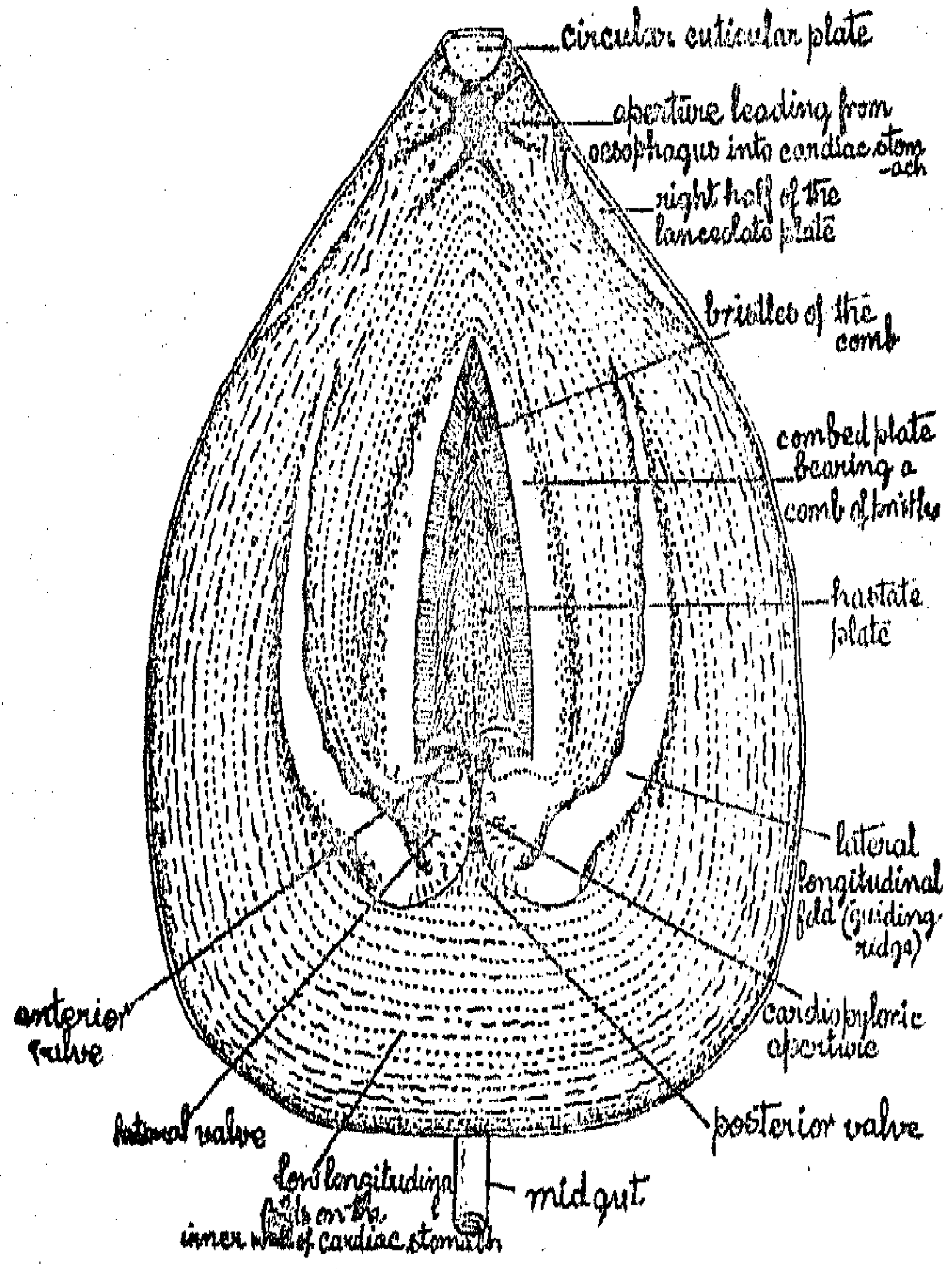

circular cuticular plate
aperture leading from oesophagus into cardiac stomach
right half of the lanceolate plate
bristles of the comb
combed plate bearing a comb of bristles
hastate plate
lateral longitudinal fold (guiding ridge)
cardiopyloric aperture
posterior valve
midgut
low longitudinal folds on the inner wall of cardiac stomach
lateral valve
anterior valve

Fig. 246. Inner view of the cardiac stomach exposed by a middorsal incison and reflection of the flaps [After Patwardhan].

At the posterior end of the fore-gut is the small pyloric stomach with thick and muscular lateral walls which project inwards dividing the lumen into a small *dorsal* and a large *ventral* chamber which communicate by a narrow vertical aperture. The dorsal chamber leads into the narrow *midgut*. The anterior wall of the pyloric stomach is lined by a pair of thin cuticular plates. The floor of the pyloric stomach is formed by a pair of thick cuticular plates each having a concave lateral surface. In section, the two plates appear |\–shaped with a high median ridge bearing long setae at its posterior end. The entire surface of these two plates bears a series of alternating ridges and grooves; the grooves are roofed over by the comb-like bristles of the ridges. A thick cuticle covered with closely-set short bristles lines the lateral walls of the ventral chamber. The lateral walls of the ventral chamber remain pressed against the lateral surfaces of the |\—shaped plate of the floor forming an efficient filter through which only the liquefied food can pass. The |\–shaped plate of the floor of the pyloric stomach is known as the *pyloric filter plate*. Close behind the filtering apparatus are found two openings of the hepatopancreatic ducts; these openings are guarded by setae. From the midgut food cannot enter back into the pyloric stomach due to specific arrangement of setae. Large particles are checked from entering the hepatopancreatic ducts.

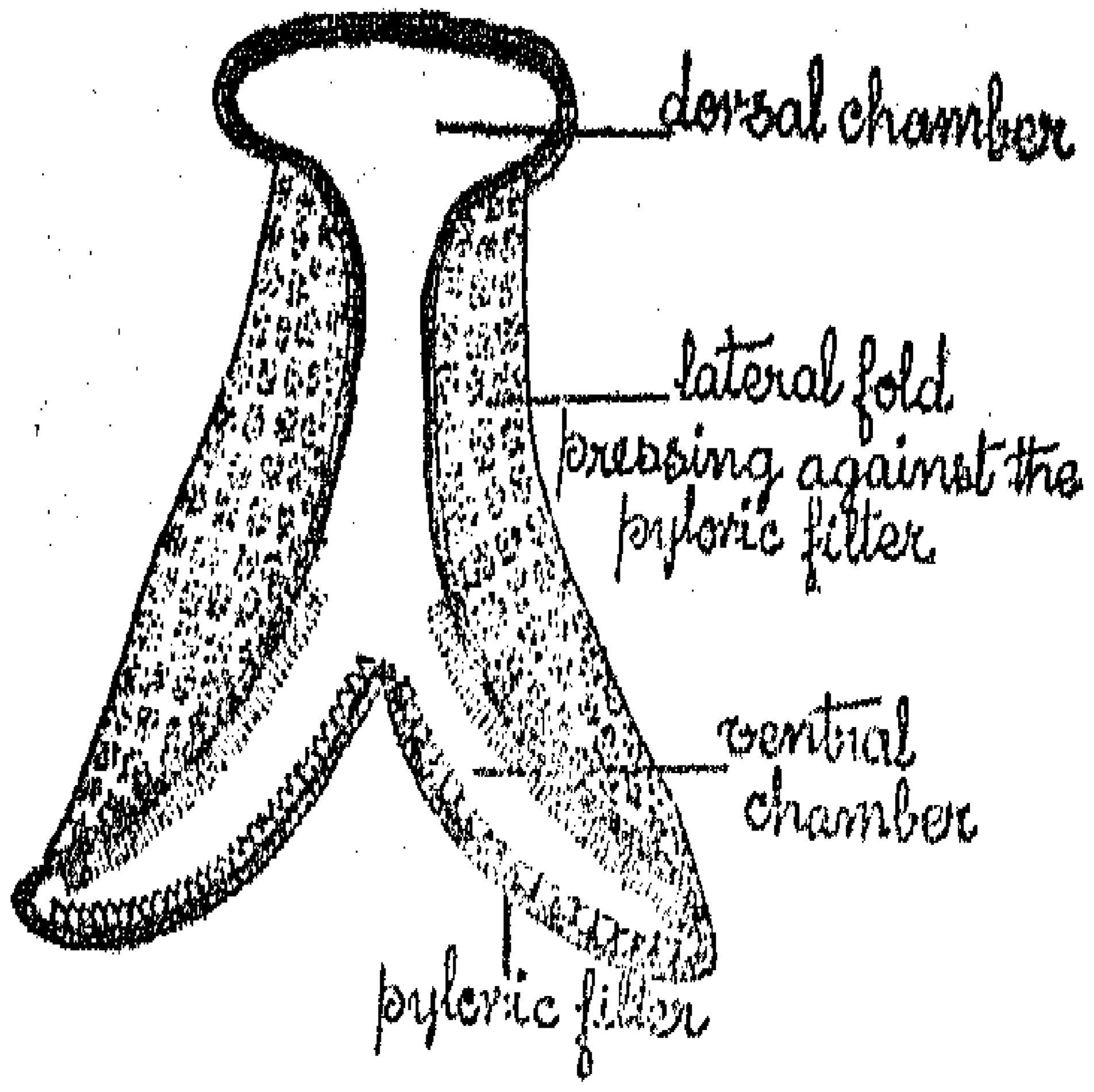


Fig. 247. A transverse section of the pyloric stomach (After Patwardhan).

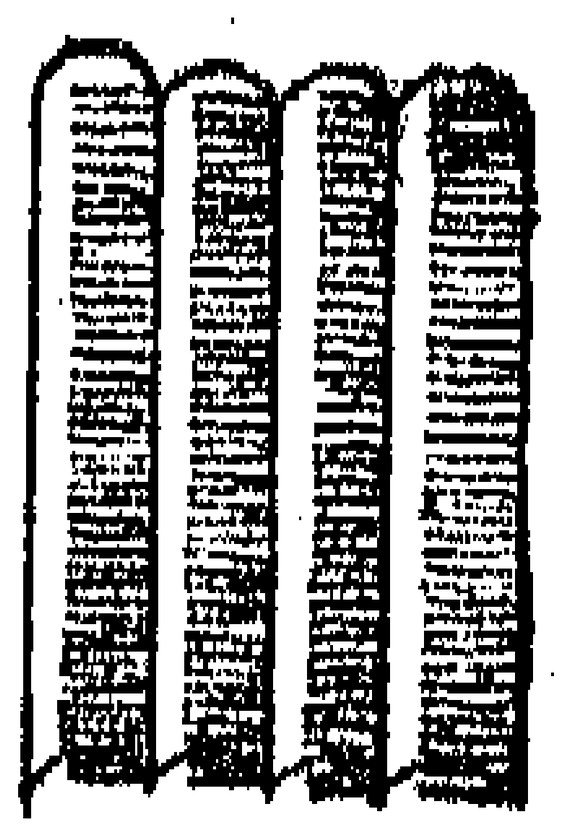


Fig. 248. A portion of the pyloric filter showing the longitudinal ridges and comb like bristles hanging over the intermediate grooves.

Liquid food containing fine particles is received into the ventral pyloric chamber from the lateral grooves (on each side of the hastate plate) of the cardiac stomach. The food is filtered in the pyloric filter apparatus and the filtrate enters the hepatopancreatic ducts; the rest of it (containing the larger undigested or the indigestible particles of food) goes into the dorsal chamber of the pyloric stomach and thereafter into the *mid gut* which is a lang slender tube running (between the two lobes of the hepatopancreas) through the thorax up to the 6th abdominal segment. The *hind-gut* which is only 1 to 1·5 cms long is swollen into a thick muscular sac at first which posteriorly becomes a narrow tube opening on a raised papilla by the *anus* provided with tumid lips for its closure and a sphincter muscle for its opening.

The **hepatopancreas** (which consists of numerous glandular tubules branching in a racemose fashion held together by connective tissue) (i) secretes digestive ferments which digest carbohydrates, proteins and fats, (ii) absorbs food material, a function also performed by the mid gut and (iii) *stores glycogen, fat* and *calcium.* Thus *it* performs the functions of the liver, the pancreas and the small intestine of higher animals.

Feeding *Palaemon* feeds upon algae, moss, weeds, small insects and debris etc. The chelate legs assisted by the 3rd. maxillipedes convey the food particles to the mouth where the second maxillipeds hold them by their median cutting plates so that the incisor processes of the mandibles can cut and tear the food. The incisor process helped by the *labrum* (upper lip) pass the food pieces of a suitable size into the buccal cavity. The gnathobases of the maxillipeds, maxilliulae and maxilla transfer small food pieces to the mouth. Inside the buccal cavity the molar processes of the mandibles projecting from the sides crush the food between them and the masticated food goes to the oesophagus and then into the cardiac stomach by waves of contraction in the oesophageal wall and partly by the contraction and expansion **of the cardiac stomach** which produce a sucking effect.

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43

Crustacean Larvae

Typically the crustacean hatches as a larva known as a free swimming *nauplius. Nauplius* is a small egg-shaped *larva* with an unsegmented body with three pairs of appendages: (i) uniramous *antennules* (ii) biramous *antennae* and (iii) *mandibles*: these possess *spines* towards the mouth; a median eye, a pair of *frontal glands* and *antennal glands*+; a labrum+; the alimentary canal with a *fore gut,* a *midgut* and a *hind gut.* At the posterior end two *furcal setae* are found. The *nauplius larva* is found in some members of every section of the crustacea but in many cases it represents only an embryonic stage within the egg membrane, the animal hatching at a more advanced stage known as the *metanauplius.*

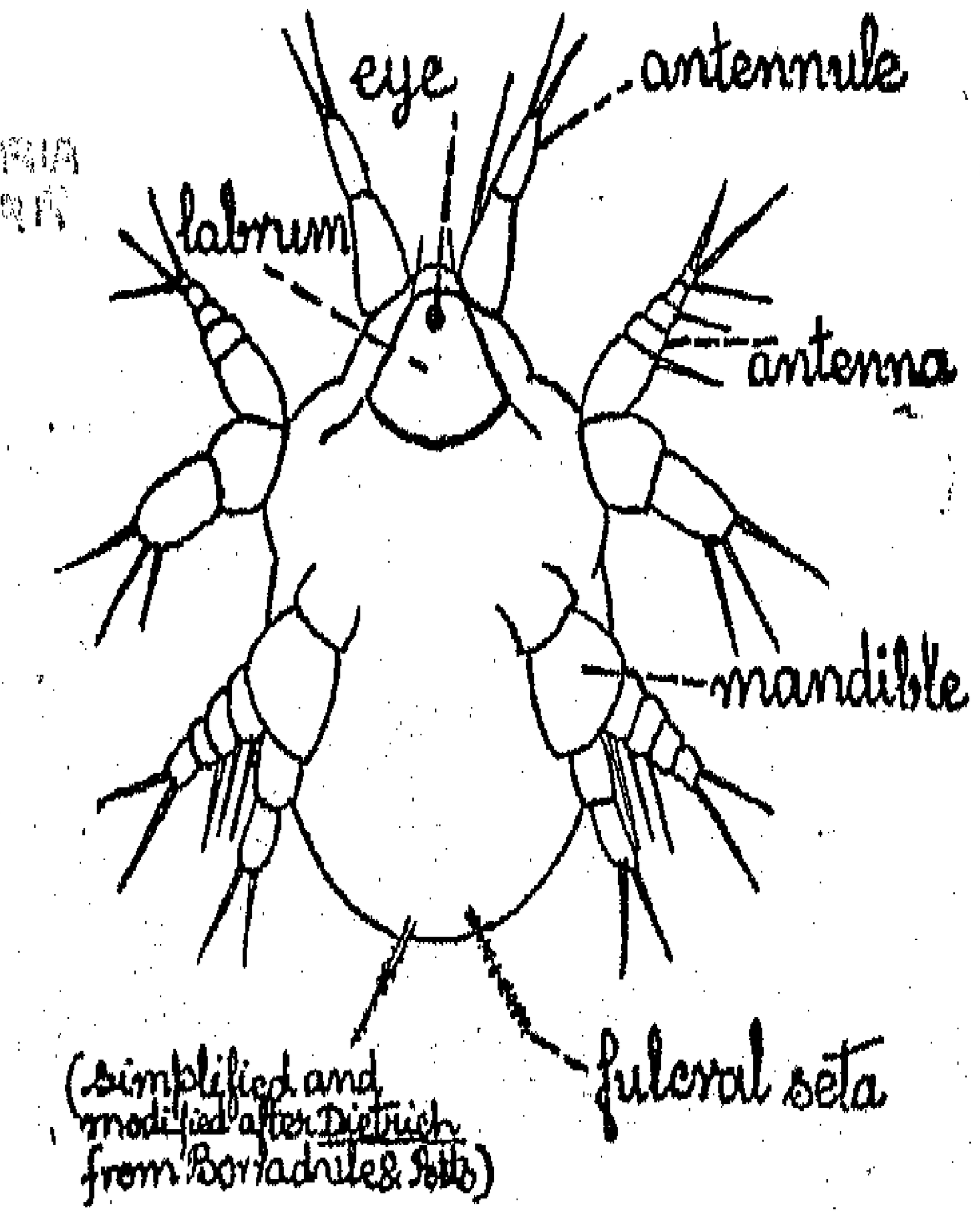

eye
antennule
labrum
antenna
mandible
fulcral seta
(simplified and modified after Dietrich from Borradaile & Potts)

Fig. 249. Nauplius larva [Read fulcral for fulcal in label above].

Metanauplius larva : Four pairs of appendages+and behind these 4 pairs of limb rudiments. The mandibles develop masticatory processes and their swimming branches diminish. A pair of papillae on the anterior margin represent the frontal organs which persist through several of the lateral stages.

The next larval stage is the **protozoaea.** The carapace covers the anterior region of the body. [The six posterior thoracic

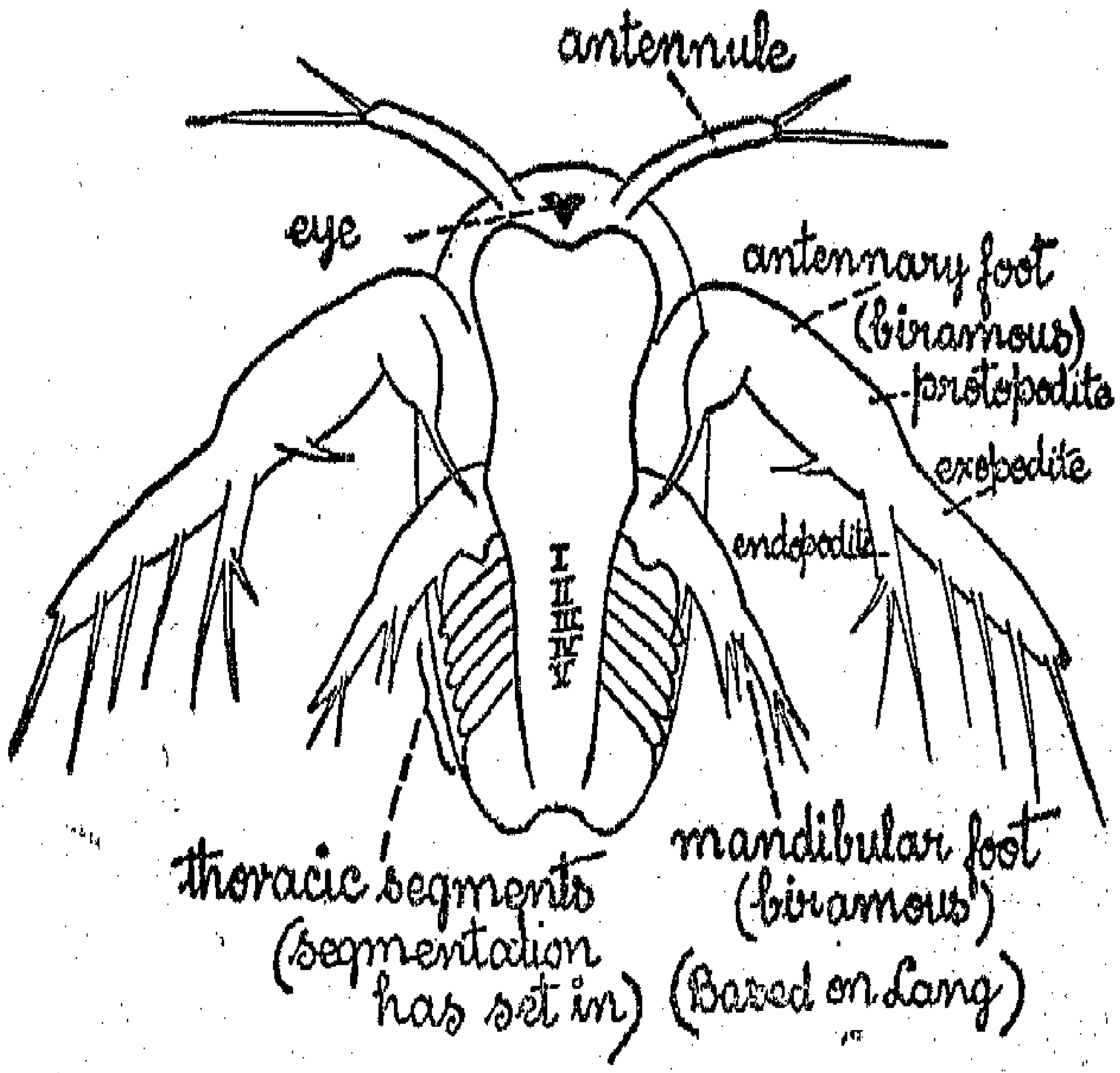

antennule
eye
antennary foot (biramous)
protopodite
exopodite
endopodite
I
II
III
IV
V
thoracic segments (segmentation has set in)
mandibular foot (biramous)
(Based on Lang)

Fig. 250. Metanauplius larva.

segments are defined though short.] The abdomen has a furcate appearance but is still unsegmented. In the later protozoaean

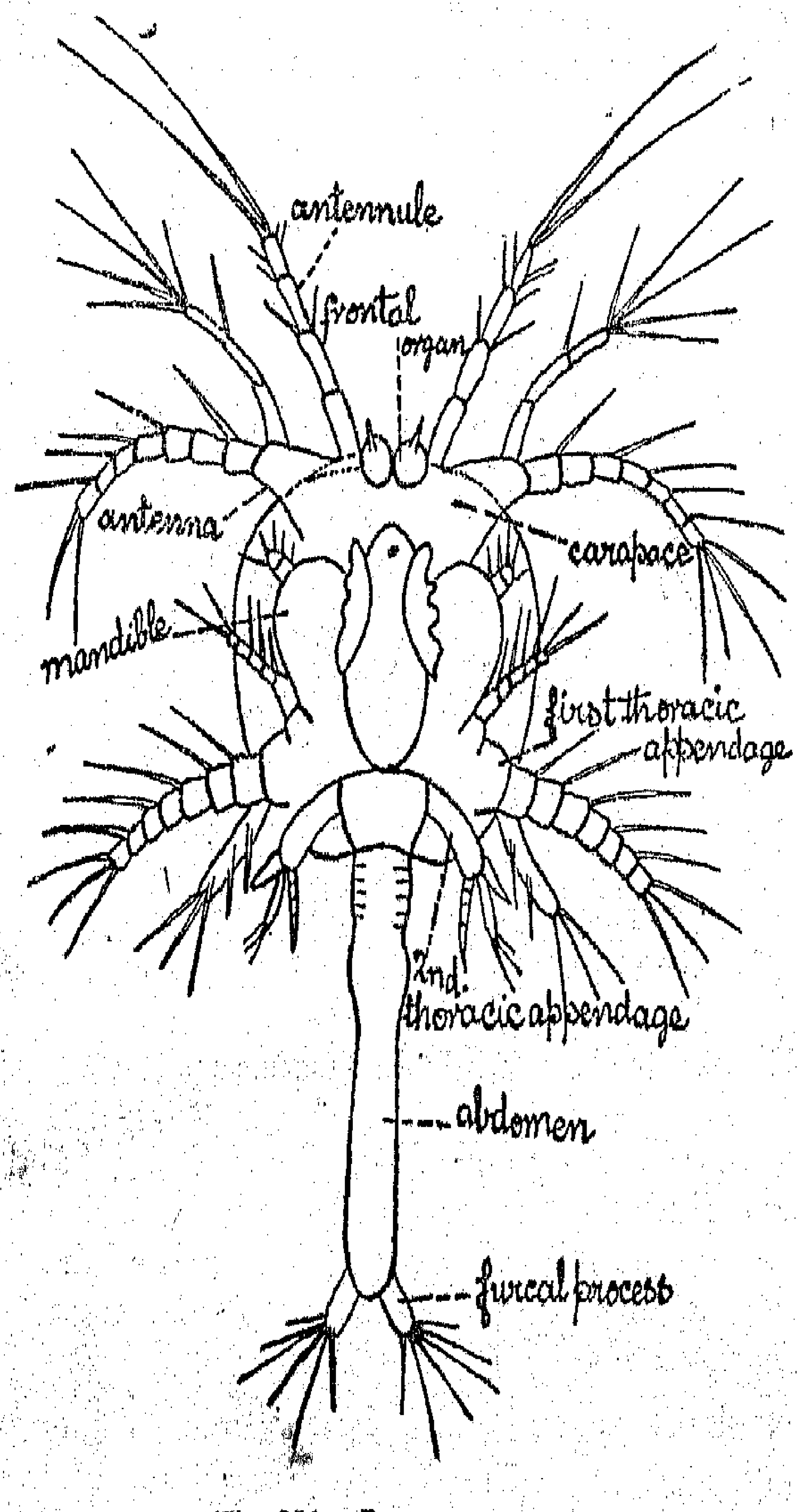


Fig. 251. Protozoaea stage.

stage the five anterior abdominal somites begin to be indicated, the sixth is not marked off from the telson. The antennae are still of use in locomotion; the *first antenna* is four jointed, the *second antenna* has an endopodite and an exopodite. The mandibular palp has completely disappeared. The first and the second thoracic appendages are biramous swimming limbs. The rudiments of paired eyes are beginning to appear beneath the carapace. The heart has only one pair of ostia. The rudiments of the 3rd. pair of thoracic limbs appear. There are three pairs of hepatic caeca.

The next stage is the **zoaea stage** in which the *paired eyes* have become free from the carapace so that the eyes are now movable and stalked. The carapace grows into a median *rostral spine.* There is a distinct *cephalothorax* and a distinctly

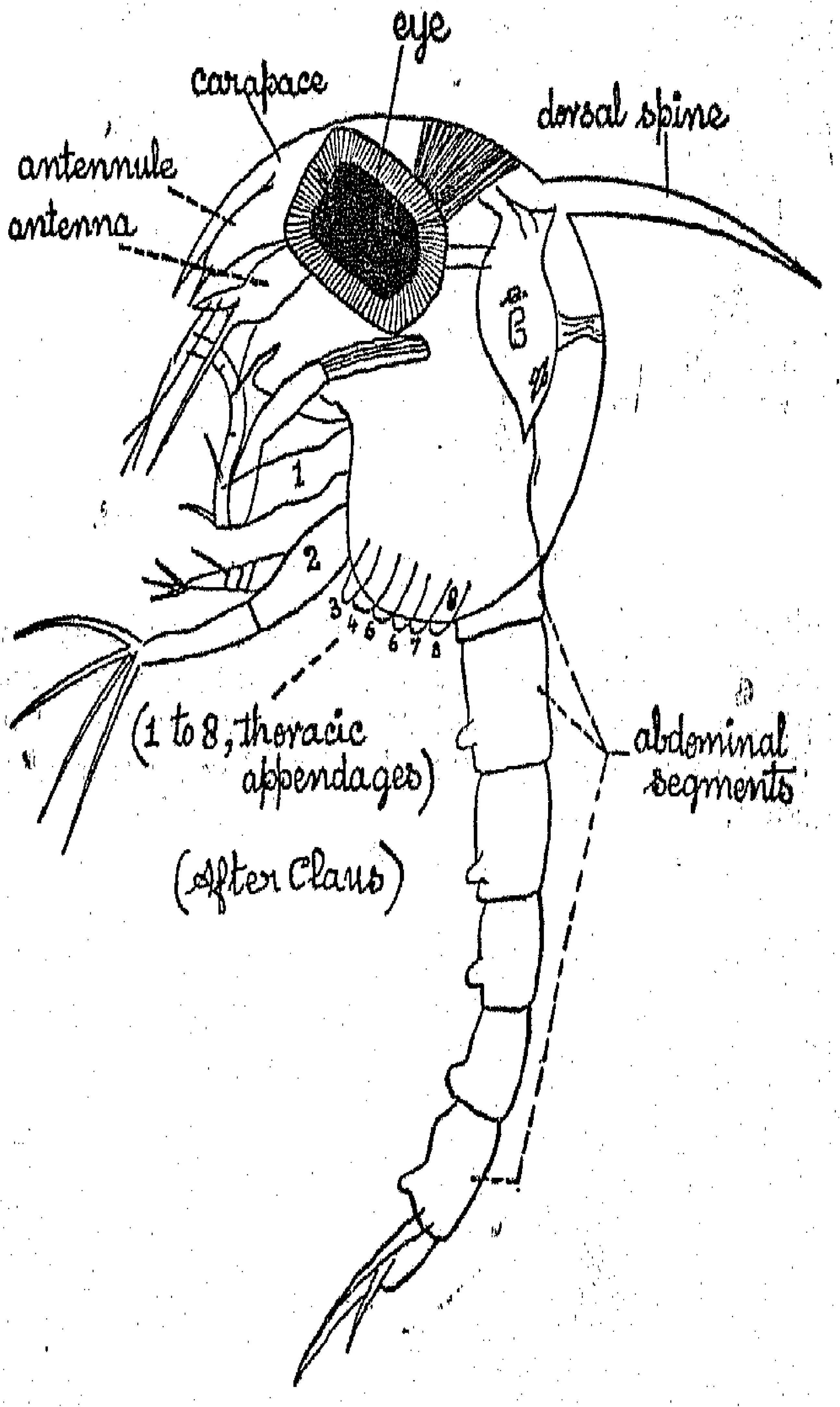


Fig. 252. Zoaea stage.

segmented movable and ventrally flexed abdomen. The first *three pairs* of *thoracic limbs* are biramous and the rudiments of remaining five are present. The five pairs of abdominal appendages are very small bud-like but the sixth pair are large and bilobed.

In crabs (Brachyura) the nauplius stage is passed through inside the egg and the embryo hatches as a peculiarly modified zoaea larva which has an immense cephalothorax produced into spines, large stalked eyes and a slender abdomen. This is followed, as a result of successive moults into the **megalopa stage** which has an extended abdomen with 5 pairs of well formed swimmerets. The appendages have assumed the form which they have in adult. By **successive moults the megalopa** gets transformed into an adult.

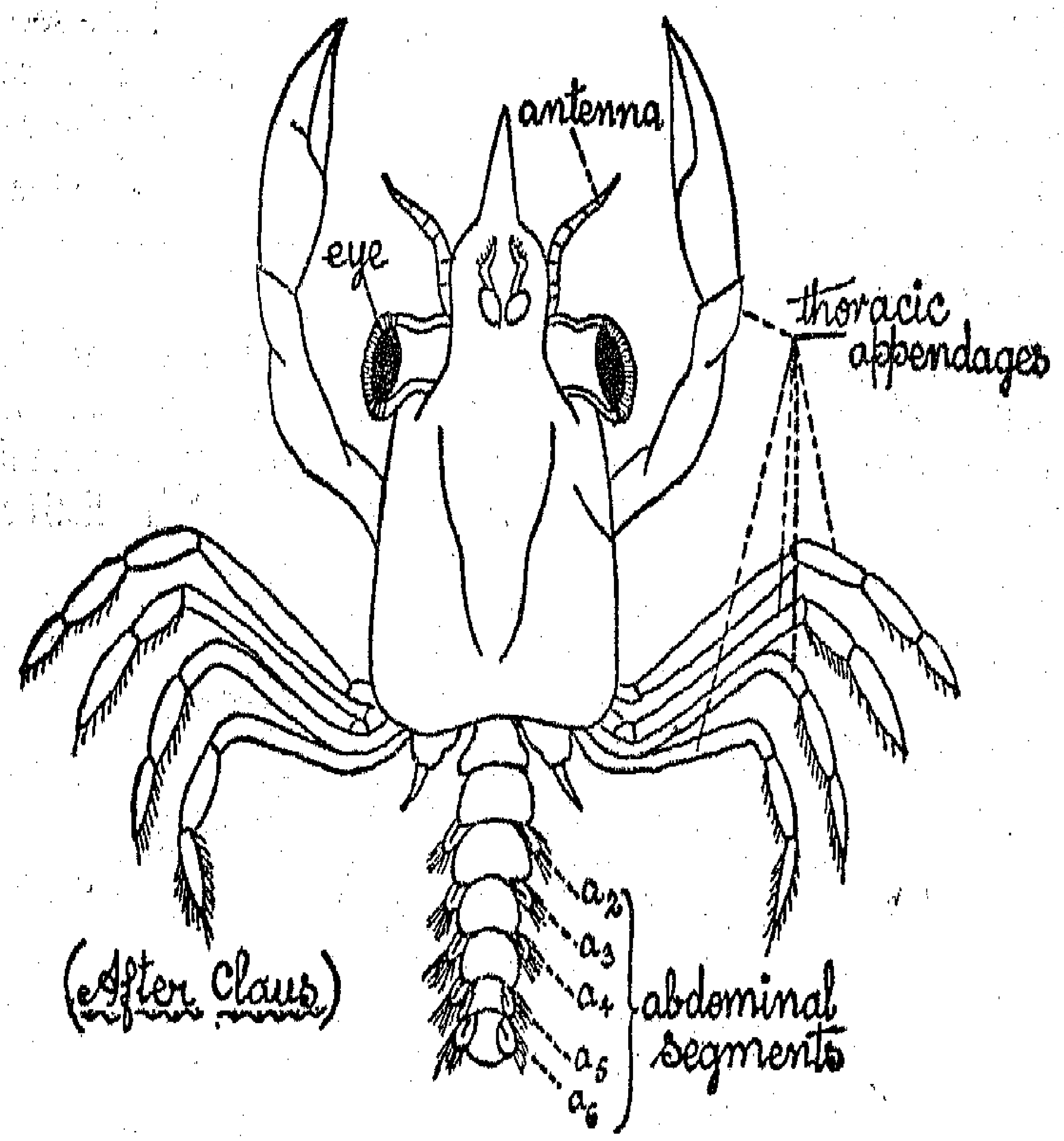


Fig. 253. Megalopa.

44

Mouth-Parts of Insects

1. **Give a comparative account of the mouth parts of the insects you have studied.** (L. U. B. Sc. Prel., 1957)

2. **Describe the mouth parts of prawn, cockroach, anopheles and housefly and show how far they are modified to their respective modes of life.** (P. C. S., 1955)

Some of the appendages borne on the head segments become modified and assume various functions associated with feeding. The appendages on the 4th, 5th and 6th head segments, which are respectively the *mandibles*, *first maxilla* and *second maxilla* become specially adapted for feeding and are known as mouth parts.

Head segment	Appendages in prawn serving as mouth parts	Appendages in insects which serve as mouth parts
4th somite	mandibles	mandibles
5th somite	maxillules (1st maxilla)	maxilla
6th somite	maxillae (2nd maxilla)	*labium* representing the fused second maxlliae

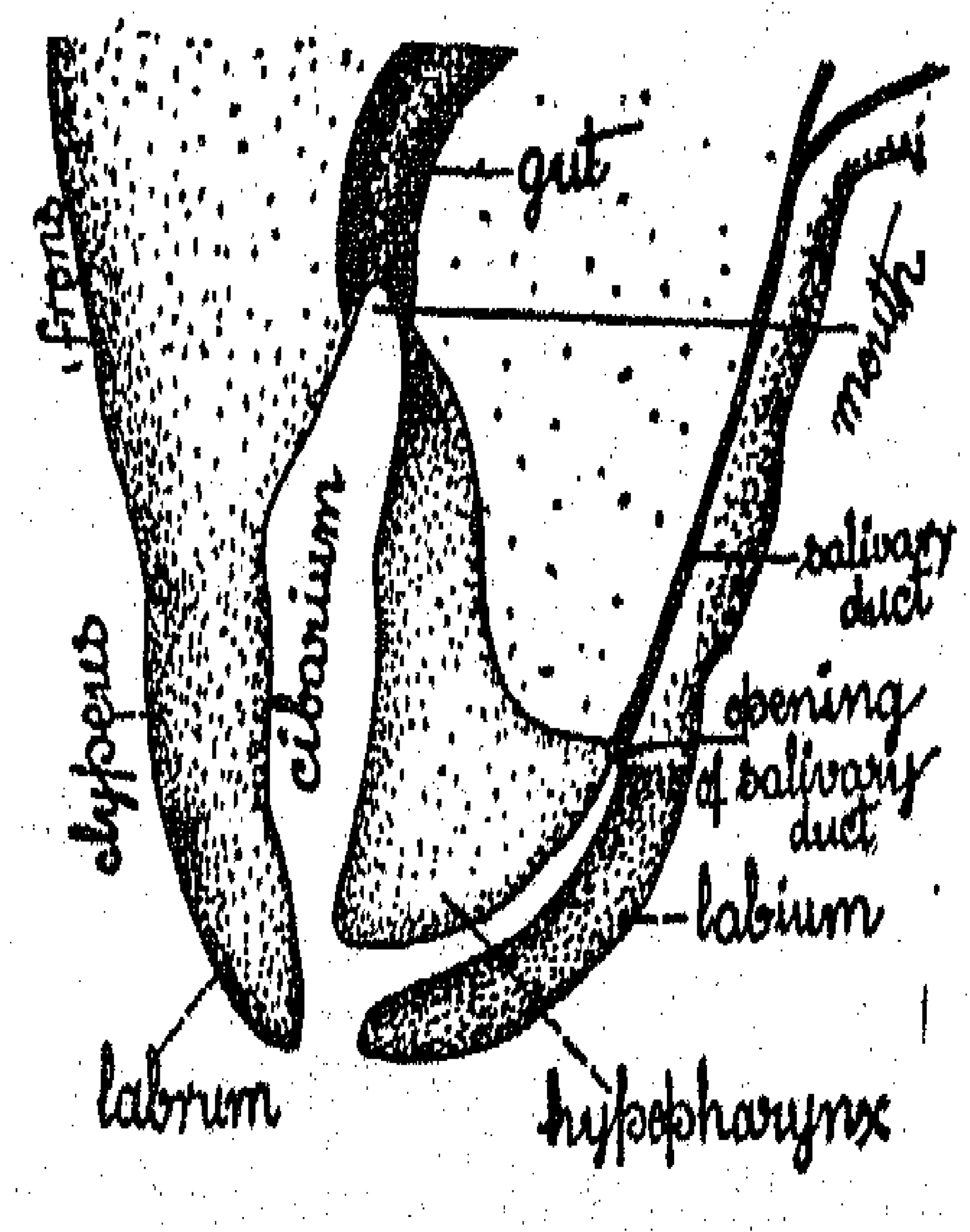


Fig. 254. Diagram showing the location of the hypopharynx.

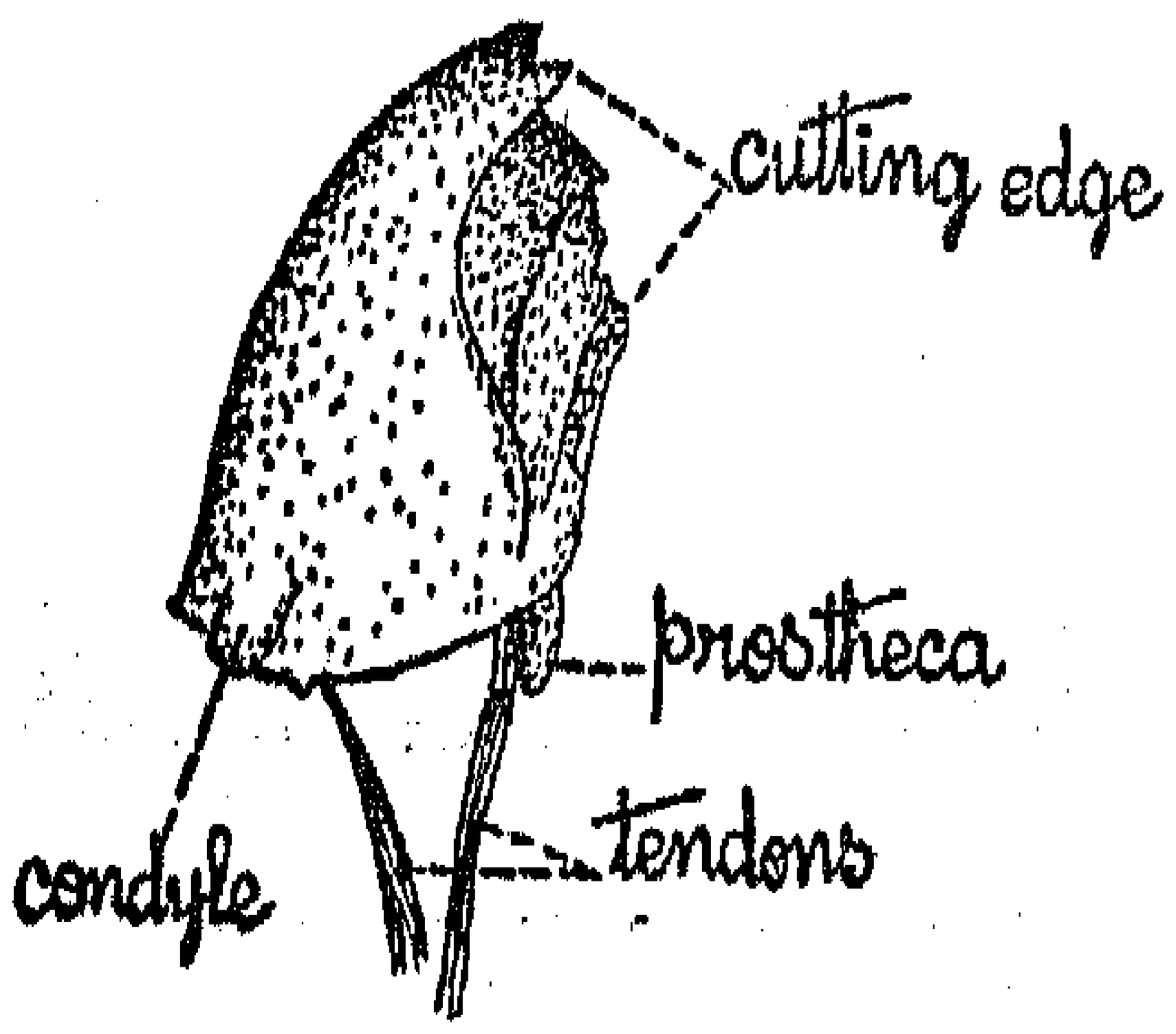


Fig. 255. A mandible of cockroach.

Thus in case of **prawn,** the three pairs of appendages namely the **mandibles, maxillules** and the **maxillae** form the three pairs of *mouth parts* or **trophi,** for these surround the mouth and are of service in dealing with the food. In case of **insects** however, besides these head appendages (mandibles, maxillae and labium), two more elements: the *labrum* and the *hypopharynx* assume the role of important mouth parts. These are not true head appendages. *Labrum* is a sclerite of the head-capsule and forms the upper lip. [In case of prawn also the mouth is bounded by the shield shaped *labrum* (upper lip)]. In case of insects the cibarial surface of the labrum is highly sensory and forms the *epipharynx.* Thus in case of insects the mouth parts include *mandibles, maxillules, maxillae, labrum-epipharynx* and the *hypopharynx.*

With the evolution of different feeding habits the structure of the mouth parts becomes modified in a variety of ways; these modifications have occurred as departures from a *basic plan* or *pattern* which is represented by the mouth parts of cockroach.

There are in all **seven types of mouth parts** found amongst the insects as described below:

1. The *chewing type of mouth parts*: The *maxillae* and the *mandibles* are fitted to work and move transversely. The *maxillary* and the *labial palps* are present. The labrum forms the upper lip and the labium forms the lower lip. On either side, there is a single stout *mandible,* the inner surface of which is

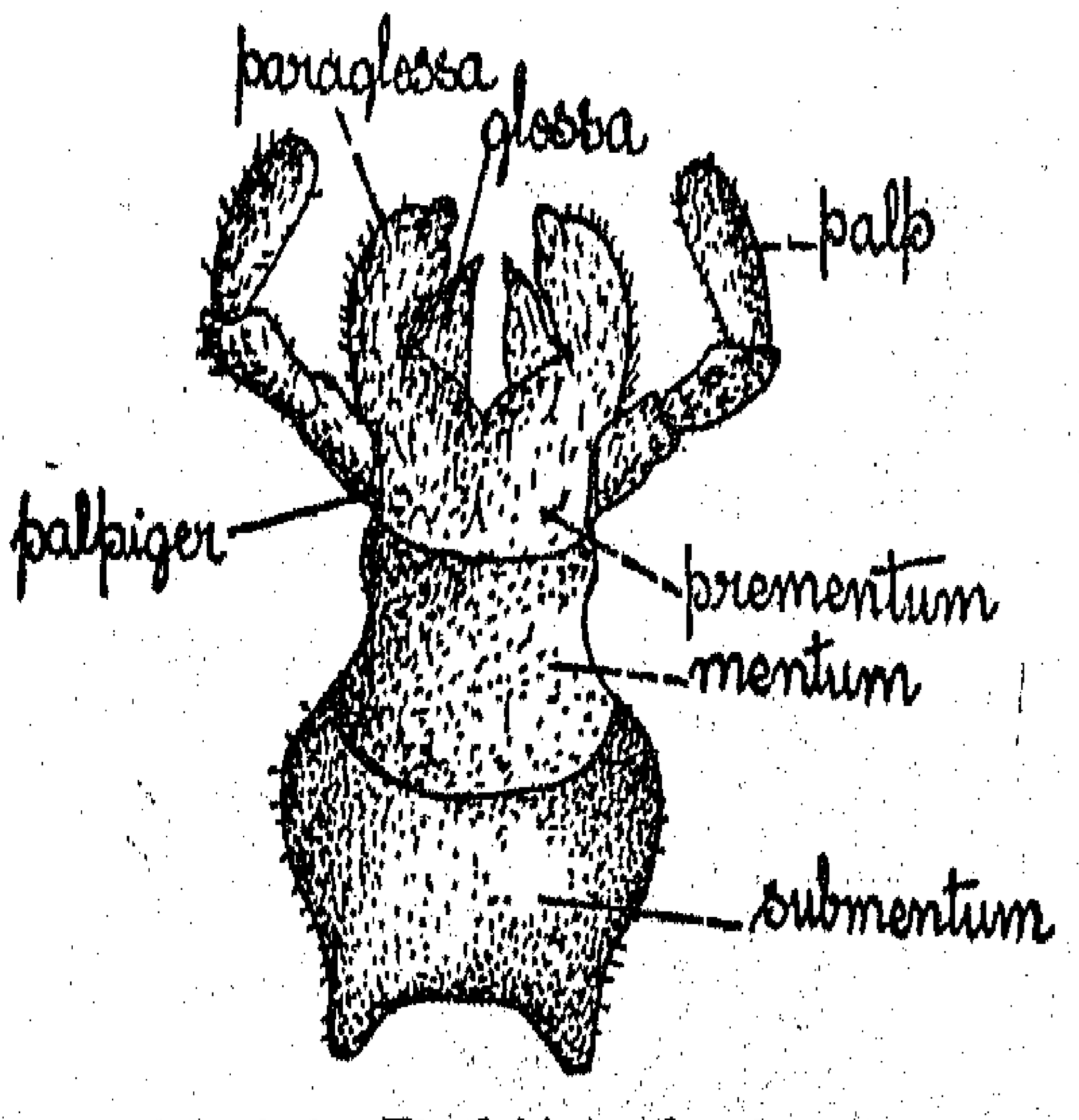


Fig. 256. The labium of cockroach.

parts first lacerate (*lacerate,* to tear, to wound) the epidermis and then suck up the exuding juice. The exuded sap is sucked up by the conical mouth and not the styles. The food-channel is inside the head-capsule lying between the labrum and the hypopharynx.

4. *Sponging type* (found in housefly)—Insects having such mouth parts always feed on exposed fluid; no solid food can be ingested by them. The *mandibles are absent,* the maxillae are represented only by a pair of palps. On the lower side of the head is a fleshy *retractile proboscis* formed by the *labium.* The end of the proboscis is modified into a large sponge-like organ, the *labella* traversed by channels known as *pseudotracheae.* The *labrum-*

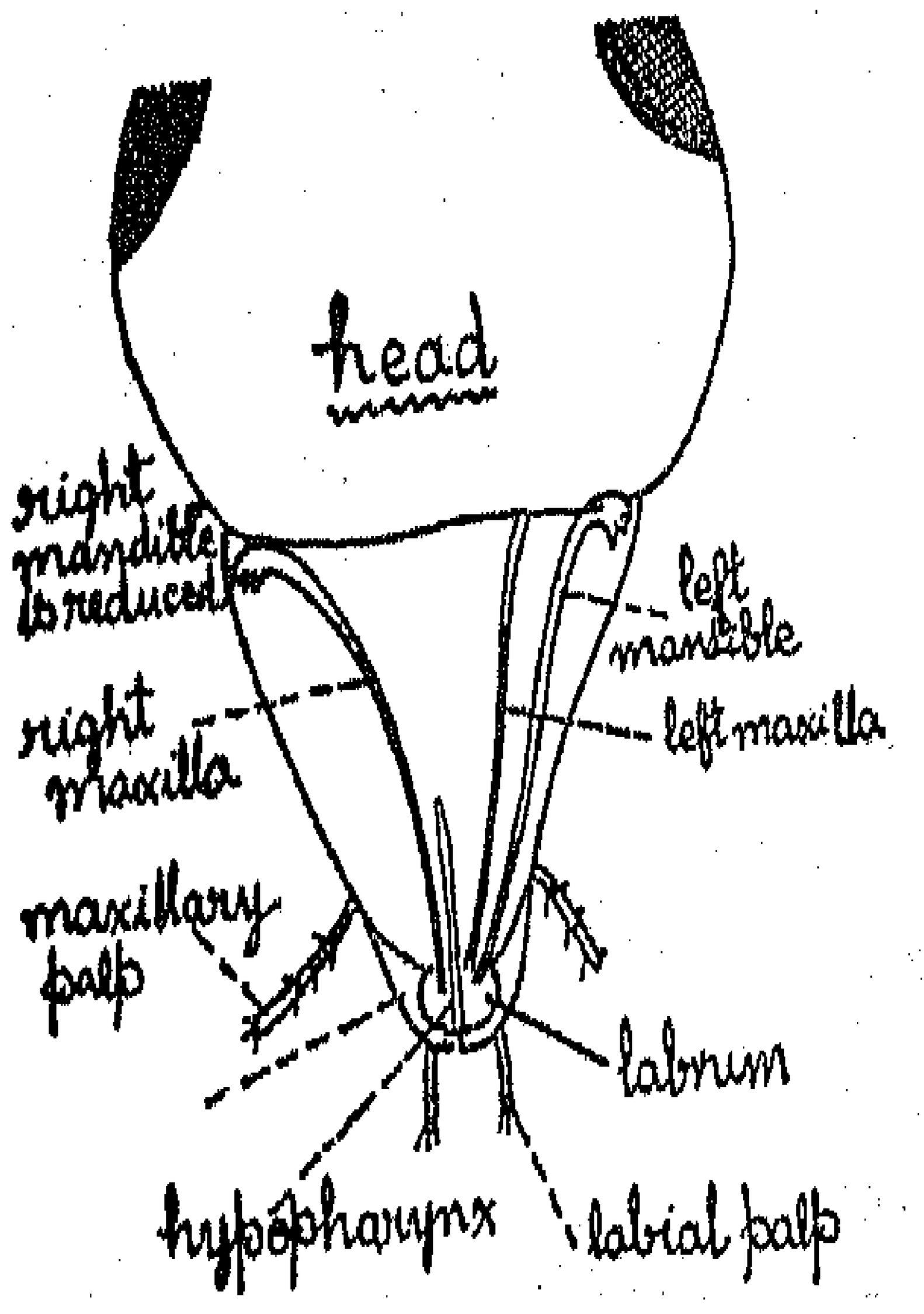
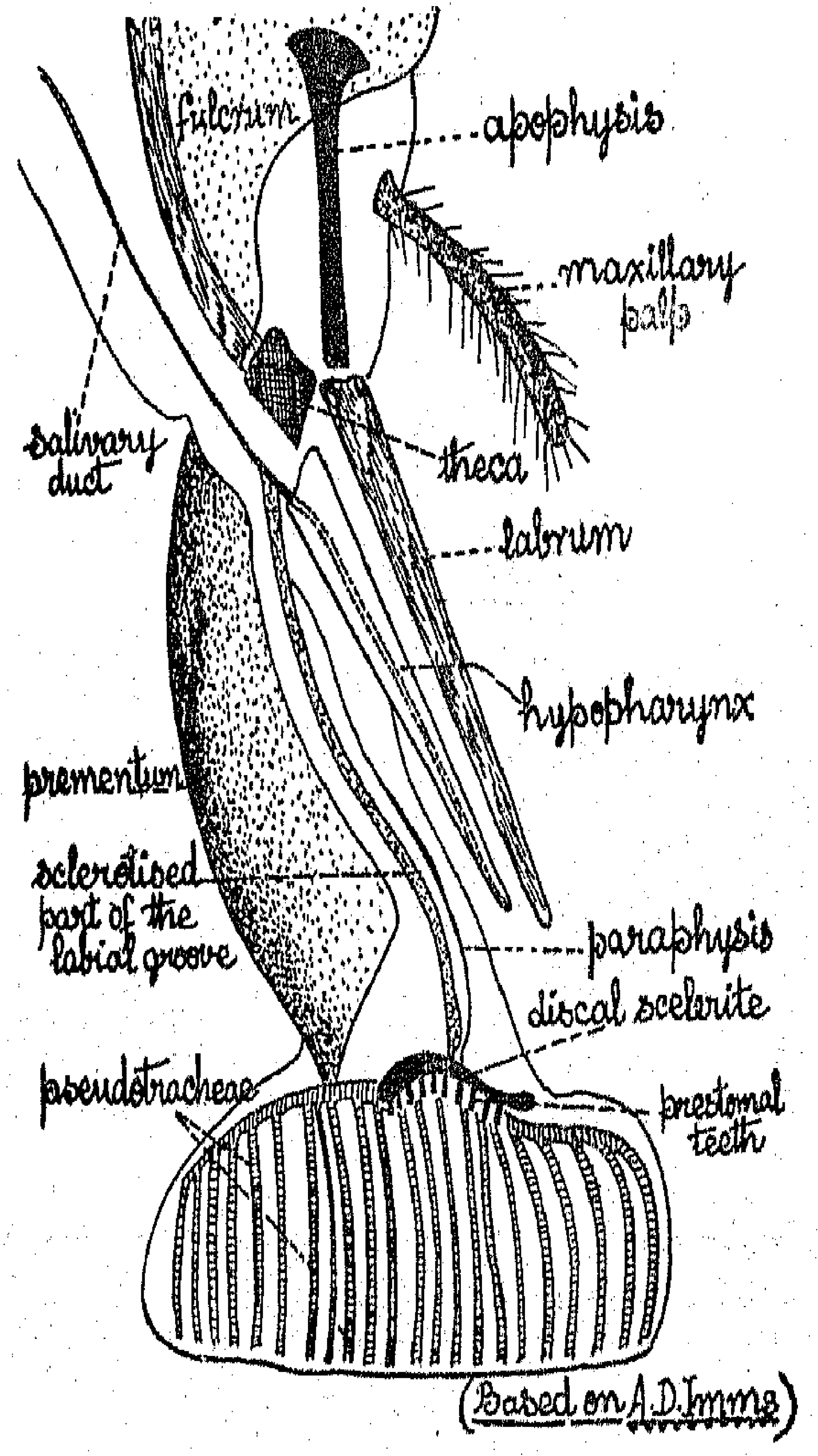


Fig. 260. Mouth parts of thrips (diagrammatic sketch)—Rasping—sucking type of mouth parts.

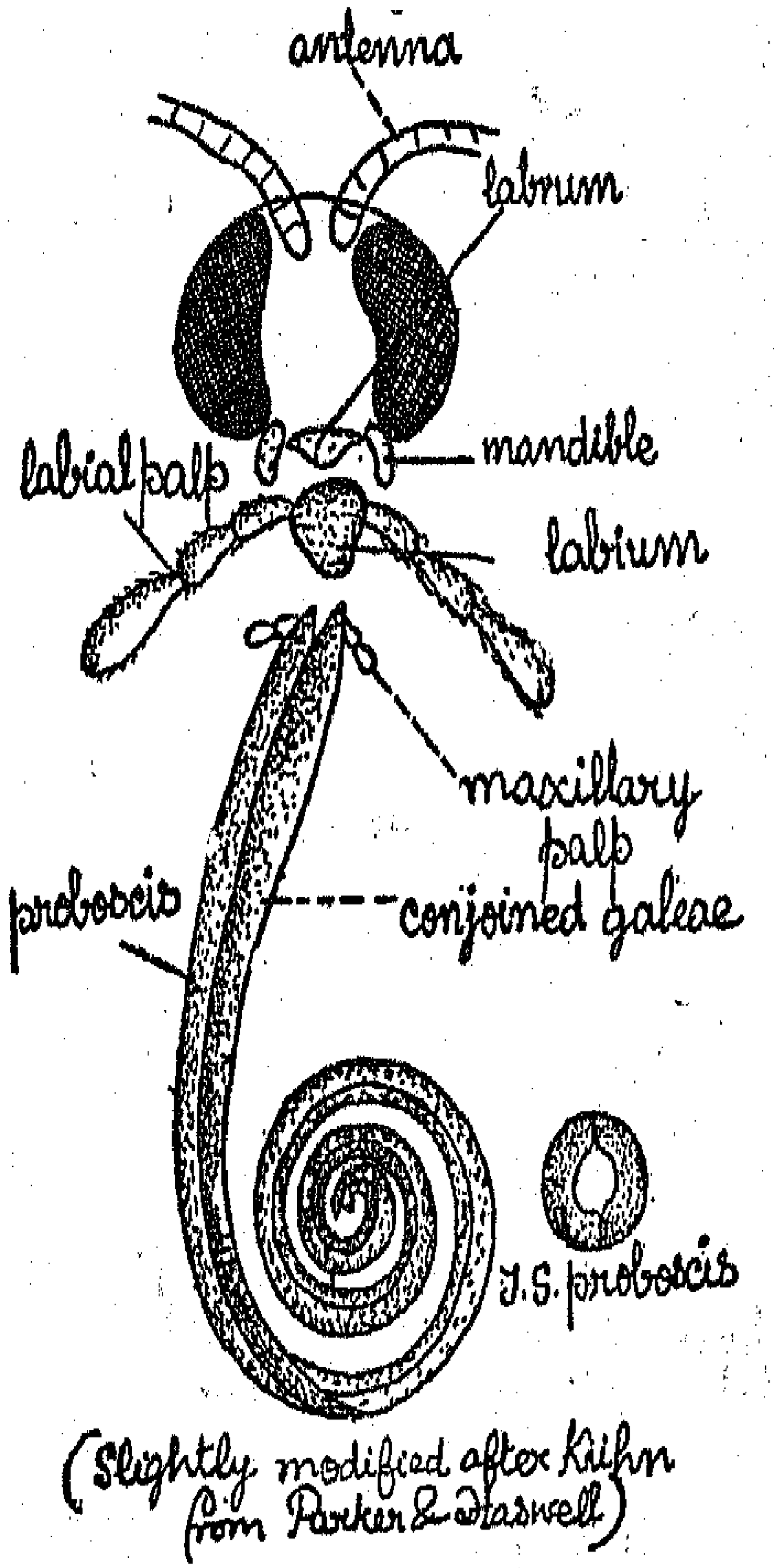


(Based on A.D.Imms)

Fig. 261. Sponging type of mouth parts of a housefly.

eyipharynx and *hypopharynx* are style-like and form the food-channel. When the *labella* is appressed to the liquid-food, it enters the pseudotracheae by capillary action. All the pseudotracheae meet at one place in the labella and from this point the liquid food is drawn through the food channel into the oesophagus.

5. *Siphoning type*—found in **moths** and **butterflies**. *Mandibles* vestigial or wanting, *labrum* greatly reduced, *maxillary palps* rudimentary, *labium* represented by a large three segmented *labial palp* and a *simple plate*. The main working parts are contributed by the maxillae; *the two very much elongated galeae have joined to form a hollow selender tube which remains coiled up in a spiral manner under the head* when the insect is not feeding. During feeding, the tube gets uncoiled and touches the exposed liquid by its tip and sucks up the food through the food channel. The proboscis has the food channel running its full length. The intake of food is effected by the action of a bucco-pharyngeal pump.



(Slightly modified after Kühn from Parker & Haswell)

Fig. 262. Siphoning type of mouth parts of Lepidoptera.

6. *Chewing-lapping type*—(found in **bees** and **wasps**). The mandibles are always present and the maxillae and labium have all the usual components; the *glossae are fused to form a broad tongue.*

In **bees**, the glossae have become elongated to form a proboscis used to extract deeply seated nectar. In case of the **honey bee**, the smooth edged mandibles are used for manipulating wax. The *maxillae* are elongated, the galeae form large thin blades; the *maxillary palps* are reduced to papillae. The labium has a long prementum and a small mentum. The *glossae* are long and terminate in a spoon-like lobe, the *flabellum*. The paraglossae are scale like at the base of the glossa. The two basal segments of the labial palp are flat and blade-like but the distal segments are unmodified. *The galeae and the labial palpi along with the glossa form a tube*, the flabellum is immersed in the food and the glossa is moved backward and forward so that the food is drawn up; the liquid food is then sucked up into the food-canal.

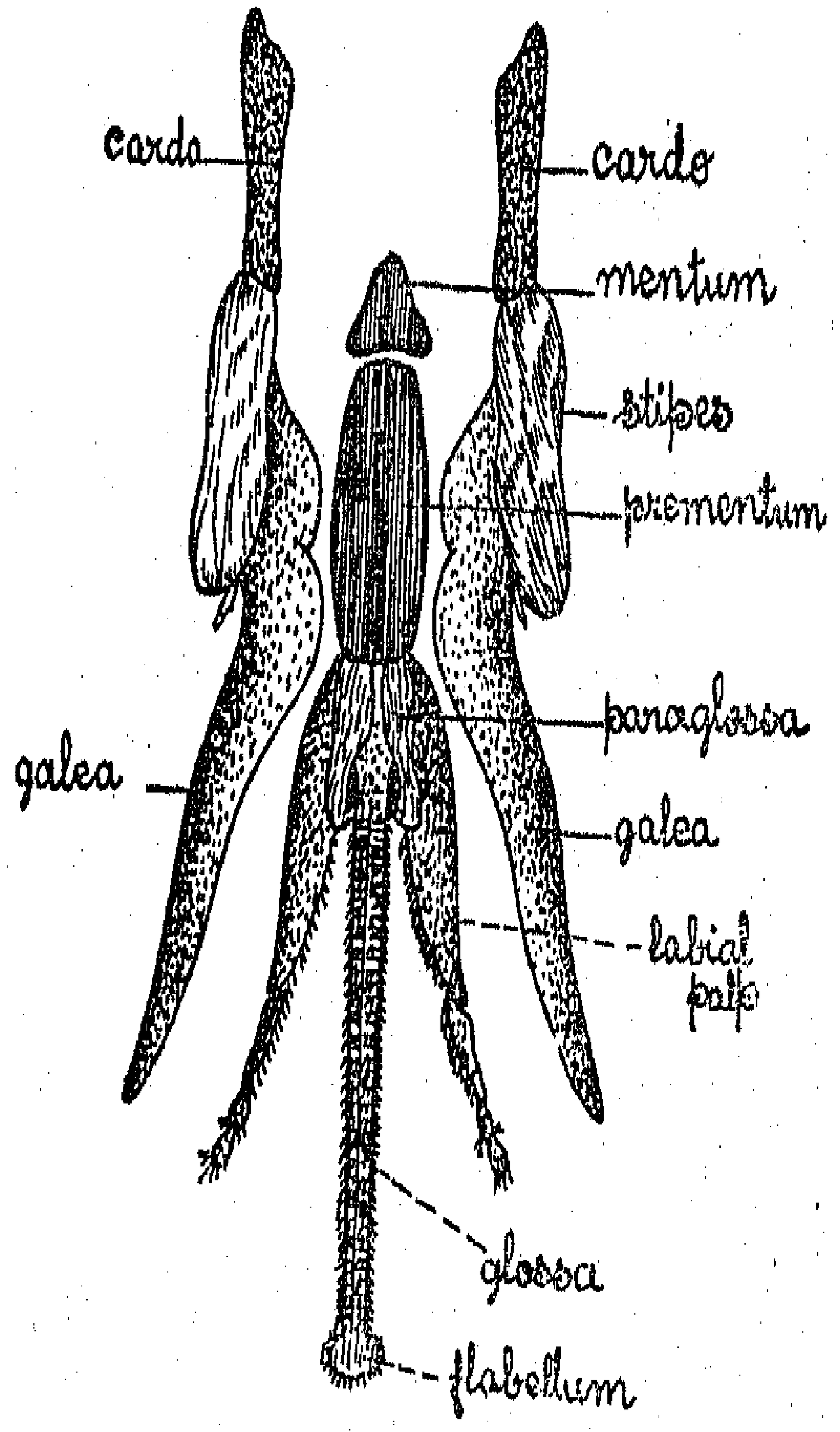


Fig. 263. Chewing-lapping type of mouth parts (ventral view, mandibles not shown).

7. *Degenerate type of mouth parts* are found in many larvae e. g. larva of house-fly (the maggot). In the maggot mouth parts are completely absent and true head segments have become invaginated into the throat. For feeding, special mouth parts have developed; the hypopharynx, clypeus and associated sclerites of head form the *cephalopharyngeal skeleton*, a sclerotised part in the beginning of the alimentary canal.

45

Metamorphosis in Insects

Metamorphosis can be defined as a series of conspicuous changes 'in form and appearance between birth and maturity or between hatching and maturity'.

Metamorphosis in insects is of two kinds:

I. **Incomplete metamorphosis** e. g. in cockroach.

II. **Complete metamorphosis** e. g. in house-fly and mosquito.

I. The emergence of the young one from the egg is known as *hatching*. When the *young one* resembles the adult insect in form and appearance except that it is smaller, lacks mature gonads and wings, it is known as a **nymph**, as found in case of cockroach. The immature stages referred to as *nymphs* more or less resemble the adults in habits and structural features so that metamorphosis consists of relatively a gradual differentiation of the adult characters. Such a metamorphosis is known as **incomplete metamorphosis, hemimetabolism or direct development.** In this kind of metamorphosis the following changes may occur: (i) the external rudiments of the wings and the external genitalia grow in size in successive *instars*; (ii) the rudiments of the generative organs grow and their ducts develop (iii) growth occurs in the eyes, more ommatidia may be added on (iv) increase occurs in the number of segments in the antennae, tarsi and cerci, (v) changes in colour and proportion in size of various structures; besides other minor changes also occur in different groups. The sequence of stages in the incomplete metamorphosis is egg→nymph→imago.

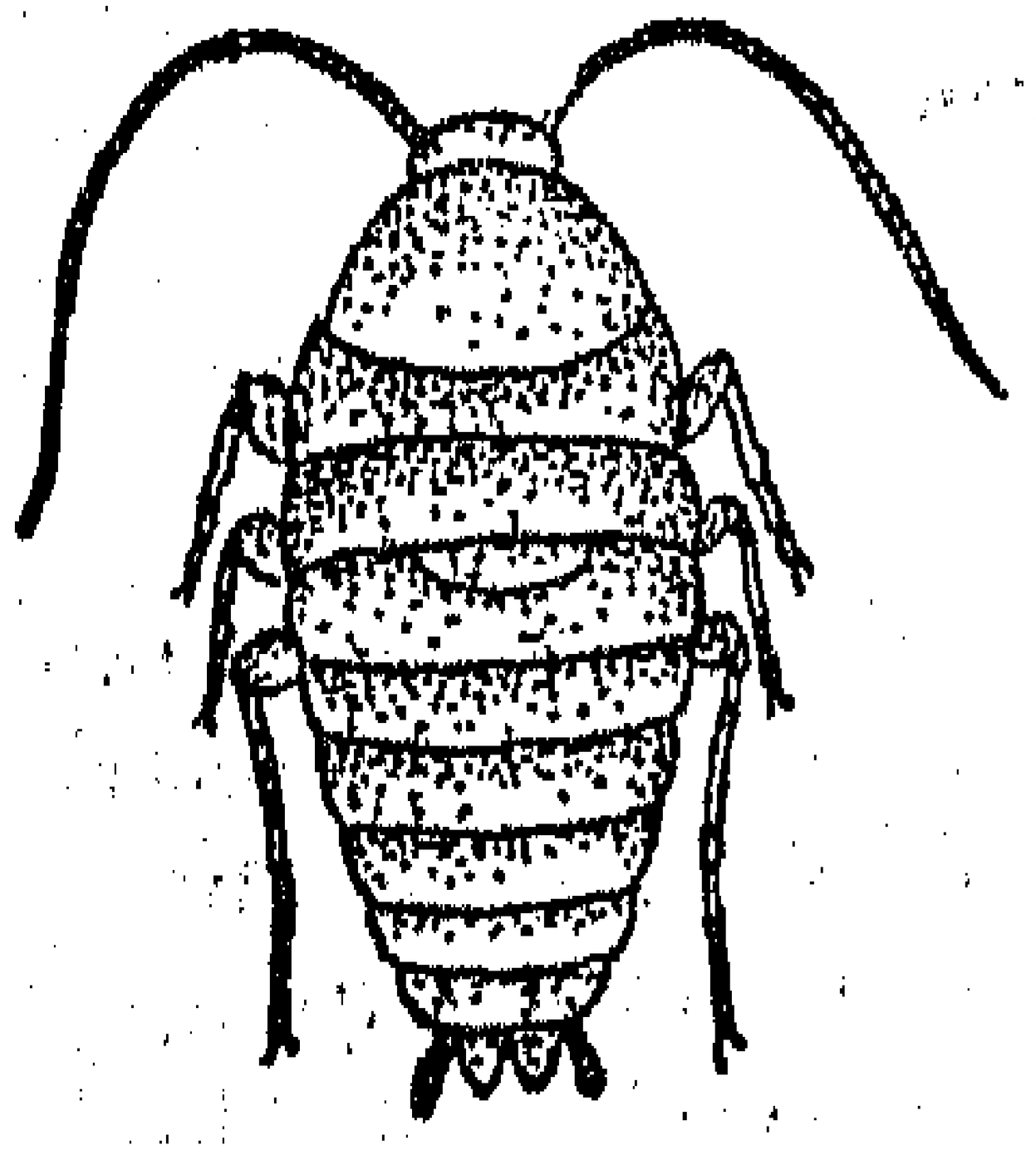


Fig. 264. An early nymph of cockroach.

Insects always grow in cycles or phases and growth in them cannot be a continual process due to the hard cuticular exoskeleton. The nymph casts off the cuticle at intervals to accommodate the growing tissues. The process of shedding or casting off the cuticle at intervals is known as **ecdysis** or moulting. The old cuticle become separated off because the underlying epidermal cells enlarge and divide. After the old cuticle is cast off the epidermal cells start secreting fresh cuticle. Immediately after the ecdysis, the insect has a soft cuticle and at this time it

grows in volume. The cuticle becomes hard in course of time. The time-periods between any two successive moults are known as *stadia*. The form of the insect in a particular stadium is known as *instar*. After its emergence from the egg, the insect is in the first instar; after the first *stadium* it moults and enters into the second instar; the 3rd., 4th. and the subsequent instars follow. After hatching, the young one assumes a number of instars and at the end of the last stadium it becomes the adult or *imago*.

In case of cockroach, there are *ten* instars; the different instars differ only in size and growth extent of various organs, particularly gonads, wings and the body size. In earlier stages, the males as well as the females have anal styles but later on the anal styles of females are absorbed. The adult females have no trace of anal styles. All the stages in the metamorphosis of cockroach are terrestrial. The instars are active feeding stages and differ little from each other except in gradual development of wings and gonads. The wings develop outside the body: at the later moults, small projections from the posterior margins of the terga (on the dorsal surface of mesothorax and metathorax) make their appearance: these projections are called wing pads. At each *ecdysis*, these rudiments of wings gain in size and finally at the last moult the wings grow to their full size. By now the gonads have also matured. The adult stage (*imago*) with maximum size is now attained and no further increase in size would now occur.

[It is now definitely known that normal growth and metamorphosis is the result of a complex interplay of the *hormones* secreted by the **corpora allata** and the **prothoracic glands.** The *corpora allata*[1] secrete (i) a *juvenile hormone* also known as *neotenin* which inhibits the development of imaginal (adult) features i. e. which suppresses or tends to inhibit the change from the nymph to the adult stage and (ii) a *gonadotrophic hormone* which helps in the maturation of ovaries and accessory glands of male.

The **prothoracic gland**, on being activated by the neuro sensory cells of the brain secretes the *moulting hormone* also known as *ecdysone* which induces the insect to moult and under its influence causes the sequence of nymphal instars. In the advanced instars, the juvenile hormone is no more produced and as a result the imaginal characters gradually appear till finally the adult instar is attained.]

II. When the newly hatched young one differs remarkably in form and appearance from the adult, it is known as a

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[1] For the details of corpora allata, the prothoracic glands and their hormonal action see pages 975 and 976 of *A Text Book* of *Invertebrate Zoology* by **Murli Manohar Saxena** (1963 Edition.)

larva. **Complete metamorphosis** is characterised by the presence of a larva which has no external trace of wings and which differs immensely from the adult in structure and habits; a series of active feeding larval instars are found which more or less resemble one another; the last larval instar is followed by an *apparently* resting *pupal instar*, for it does not feed; the pupa moults into the adult. The sequence of stages in the complete metamorphosis is: egg→larval instars→pupa→imago (adult). As the pupal instar commences, two main kinds of changes also start:

(i) *histolysis* or the destruction of larval organs and tissues; and
(ii) *histogenesis* or the differentiation of adult structures.

During the entire pupal stage, both *histolysis* and *histogenesis* go on simultaneously and as a result at the conclusion of the pupal instar the full-fledged imago emerges and wings its way through the air.

The **complete metamorphosis** also known as **holometabolous development** (holometabolism) or **indirect development** occurs in the Endopterygota (Lepidoptera, Diptera, Hymenoptera). As examples of holometabolism we will briefly refer to the metamorphosis in case of housefly *Musca* and mosquito.

In case of *Musca*, there are three larval instars. The newly hatched larva represents the *first instar*, it moults giving rise to the *second instar*, it moults and gives rise to the *third instar* which changes into pupa without moulting; the last larval cuticle persists and forms the outer protective covering of the pupa known as *puparium*.

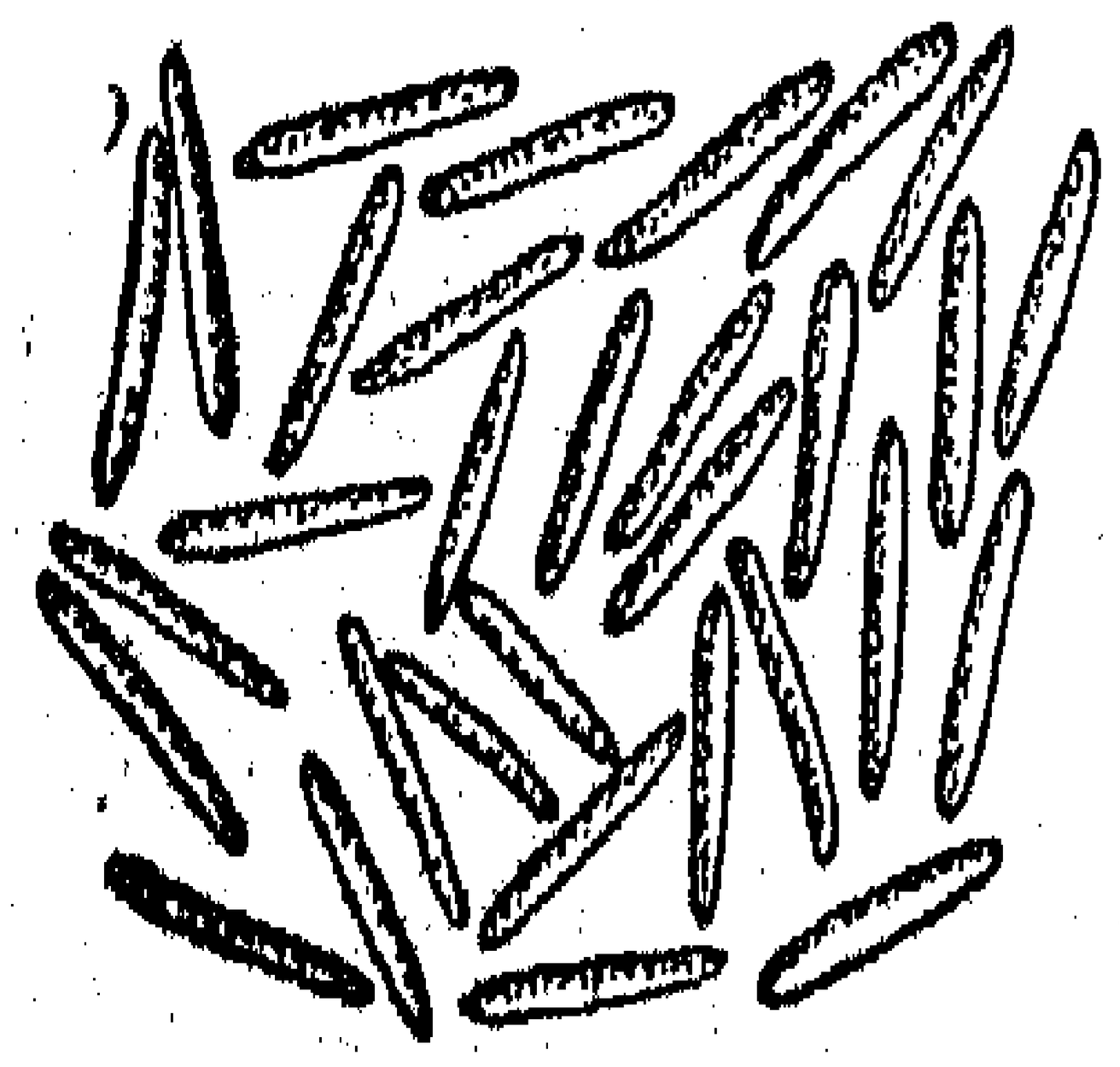
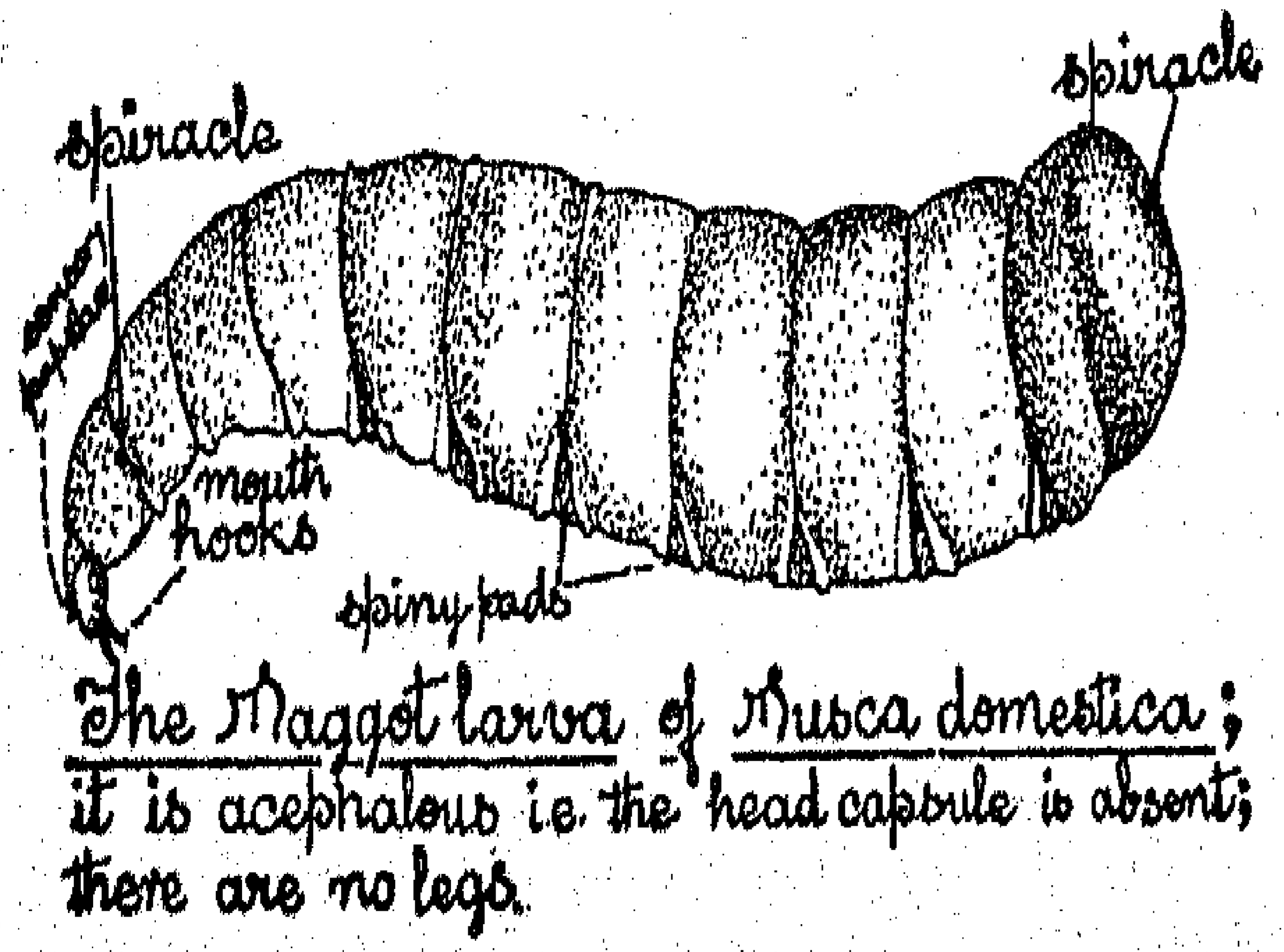


Fig. 265. Eggs of Musca domestica.



The Maggot larva of Musca domestica;
it is acephalous i.e. the head capsule is absent;
there are no legs.

Fig. 266. Maggot larva of the housefly.

The larva of housefly is known as the *maggot larva*.[1] The fully grown *maggot larva* is about 12 m. m. long and has besides cephalic segment, twelve segments, The maggot is *acephalous* and *apodous*. [*Acephalous*, the head capsule is reduced in these larvae; true mouth parts are atrophied and are replaced by the *cephalopharyngeal skeleton*. *Apodous*, lacking legs completely]. It has no external wing-pads and no genital appendages. The general integument is less sclerotised and the head capsule, cephalic appendages and legs are completely reduced.

Anteriorly to the oral aperture is a hook-like *mandibular sclerite* which helps in feeding and locomotion. The food of the larva is semifluid and it lacks elaborate mouth parts. There is an *anterior pair of spiracles*, one at each side of the second segment and a posterior pair of spiracles at the posterior end of the body. The whole head-rudiment is invaginated into the thorax. The third larval instar has in each segment except the first six, ventrally placed crescentic locomotory pads. On the ventral side of the last segment is situated the *anal aperture*.

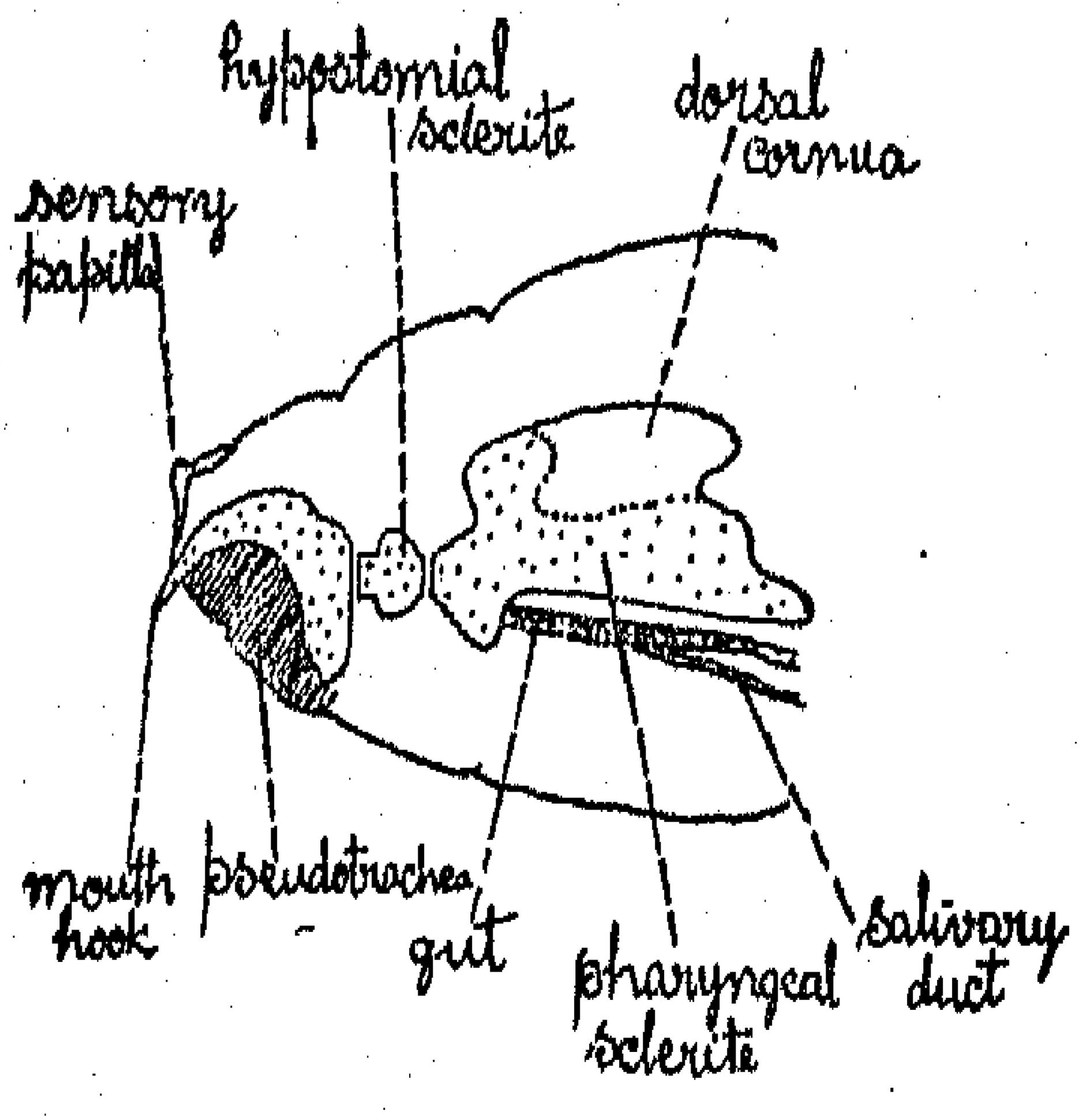


Fig. 267. Anterior end of the maggot larva showing the mouth parts and the cephalopharyngeal skeleton.

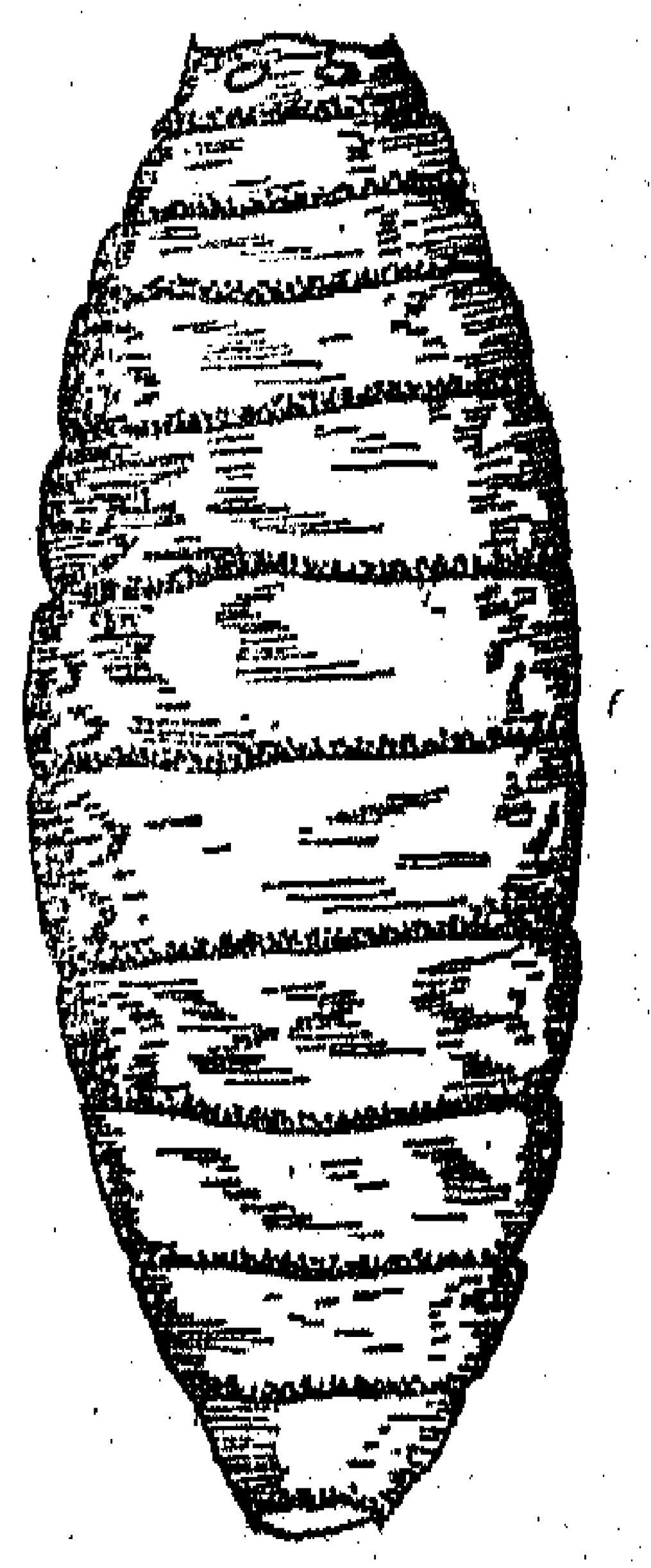


Fig. 268. Puparium of the housefly. →

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[1] "In a single breeding season, the female (after copulation) deposits eggs 5 to 6 times, each time laying 100 to 160 eggs. After 6 to 8 hrs., or more (24 hrs.), the eggs hatch and small whitish worm-like wriggling larvae known as *maggots* emerge. The housefly lays eggs in horse manure or in any other animal or plant refuse provided the medium furnishes moisture and a favourable temperature; moist human faeces may also be used. Each egg is about 1 m. m. long whitish and cylindrical. A slit occurs along one side of the edge to allow emergence of larva or **hatching**". [See *A Text Book of Invertebrate Zoology* (1963 Edition) by **Murli Manohar Saxena** pages 981 to 994 for a detailed account of the Life-history of *Musca*, the common housefly].

The larva feeds in the dung and moves about preferring the dark regions; then it travels to a dry and safe crevice and becomes transformed into *pupa* without moulting, the last larval skin itself becomes hard and forms outer protective covering of the pupa known as *puparium.*

Now the *histolysis* or the destruction of larval organs and tissues sets in; throughout the pupal instar the histolysis as well as *histogenesis* go on simultaneously. The breakdown products of the histolysis accumulating in blood furnish elements for the *histogenesis*. *The cells* from which the adult tissues develop have an unmanifested potentiality for differentiating into the imaginal (adult) structures and these cells are known as the *histoblasts*, clusters of which form the rudiments of the adult organs or the *imaginal discs*. The whole processes inside the puparium go on for three to four days. The pupal stage may last for four or five days. When the imago (the adult) is completely ready inside the puparium, the inflated *ptilinum* (an eversible head-sac: the *frontal sac* is a cephalic organ which is everted prior to the emergence of the fly; the puparium gets ruptured with the help of the ptilinum) gets everted and breaks open the puparium. After its emergence from the puparium, the fly is whitish but its exposure soon darkens it. In about a week's time or say a fortnight, the gonads become mature and the fly becomes a full fledged adult. A few days later it lays eggs.

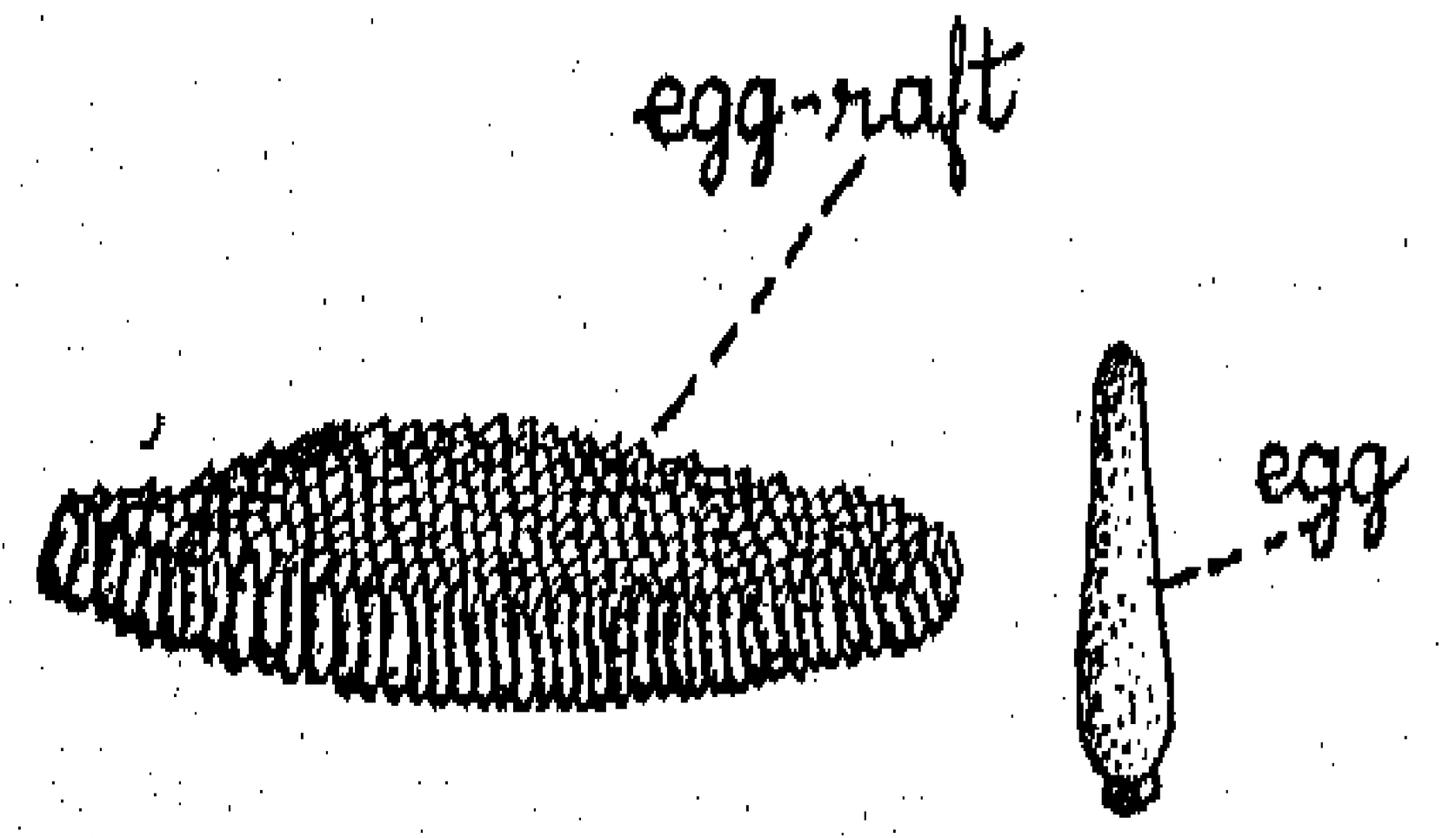

Fig. 269. The egg raft of Culex.

Mosquito (*Culex*) [After mating the female finds a ditch or any mass of stganant water and lays 200 to 300 eggs on the surface; she arranges the eggs and glues them together side by side making a 'raft' which floats on water. After 2 to 3 days, the eggs hatch and from each one of them emerges a free-swimming small transparent larva. The larva is active and it feeds and grows; it floats motionless in a slanting vertical position with its head downwards and with its rear end piercing the water surface].

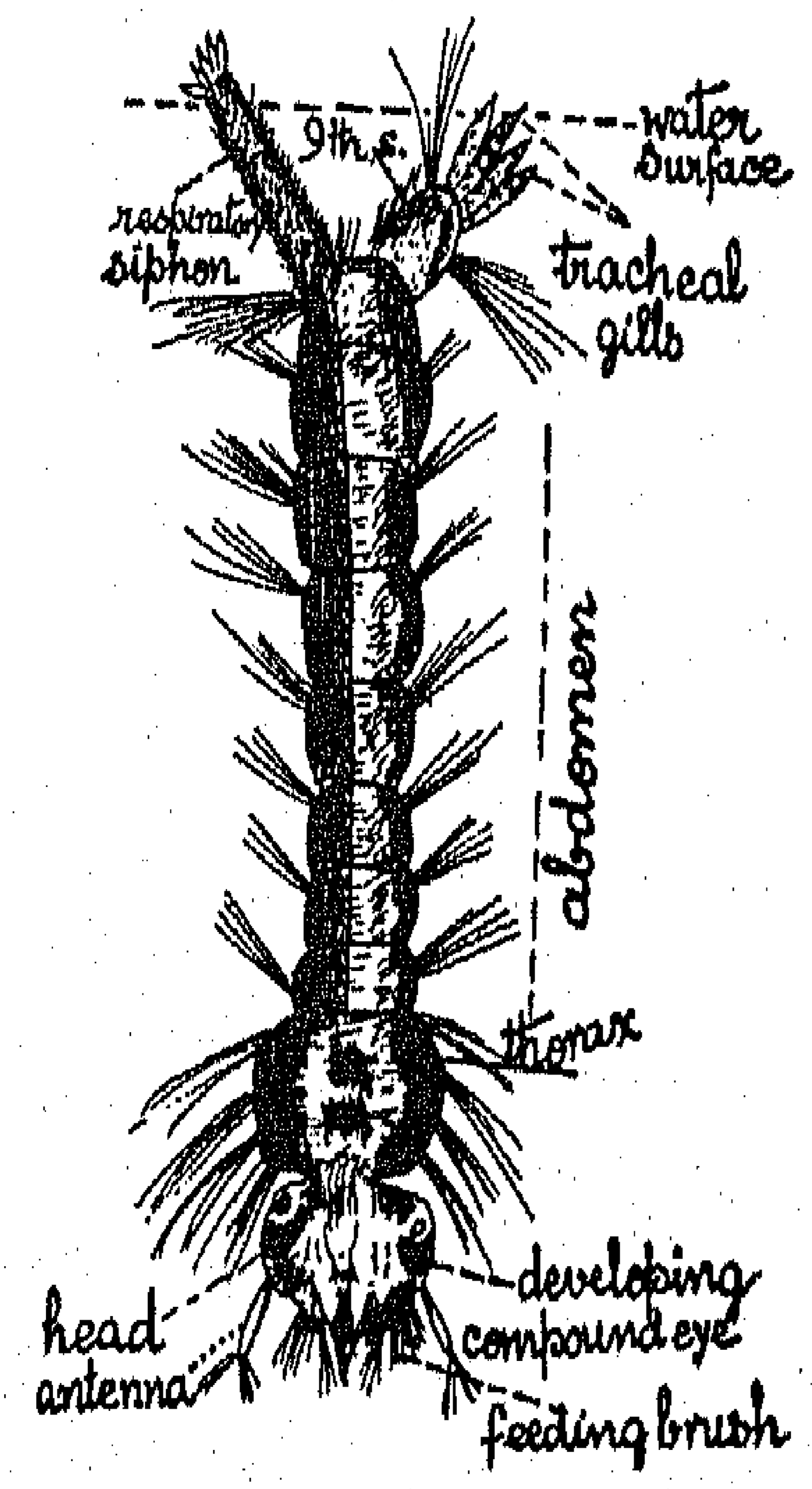

Fig. 270. The larva of Culex. The larva in fact keeps in a slanting vertical position from the water surface and not quite vertically as shown in this diagram.

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Respiration and Reproduction in Scorpion

Respiration: Four pairs of *stigmata* are found on the ventrolateral sides of the 3rd, 4th, 5th and 6th segments of the mesosoma. The stigmata lead into the *pulmonary sacs* or the *book lungs* which are chief organs of respiration in scorpions. There are in all *four pairs of book-lungs* each communicating with exterior through its own stigma. Each book-lung may be described to consist of a sac-like cavity opening obliquely on the ventrolateral side of the sternum by the *stigma*. Each pulmonary sac consists of an obliquely elongated *air-atrium* into which the stigma immediately leads and a *pulmonary chamber* which has in it 130 to 150 hollow delicate *laminae* arranged parallely to one another, being borne on a definite axis and disposed like the leaves of a book; due to this arrangement the pulmonary sac has been called as the '*book lung*.' These laminae are attached to a basal axis on the posterior mesial side of the chamber. Each lamina is hollow and is covered by a thin layer of cuticle raised into a reticular network of thickenings from which arise on the outer side obliquely arranged bristle like outgrowths due to which the adjacent laminae remain apart at a small distance leaving an air space between every two adjacent laminae. Air entering by the stigma comes into the air atrium and then prevails into these air spaces between the laminae of the lung book. In the hollow of the lamina itself flows the blood so that its blood is separated from the air only by the thin membranous wall of the laminae. The blood enters the interior of the laminae from the ventral sinus. It gets aerated or oxygenated by means of the air flowing in between the laminae. Gaseous exchange occurs entirely by diffusion through the thin membranous wall of the laminae. There is little evidence that the air is actively pumped in and out of the book-lung although it is presumed by many that there is a rythmic contraction and

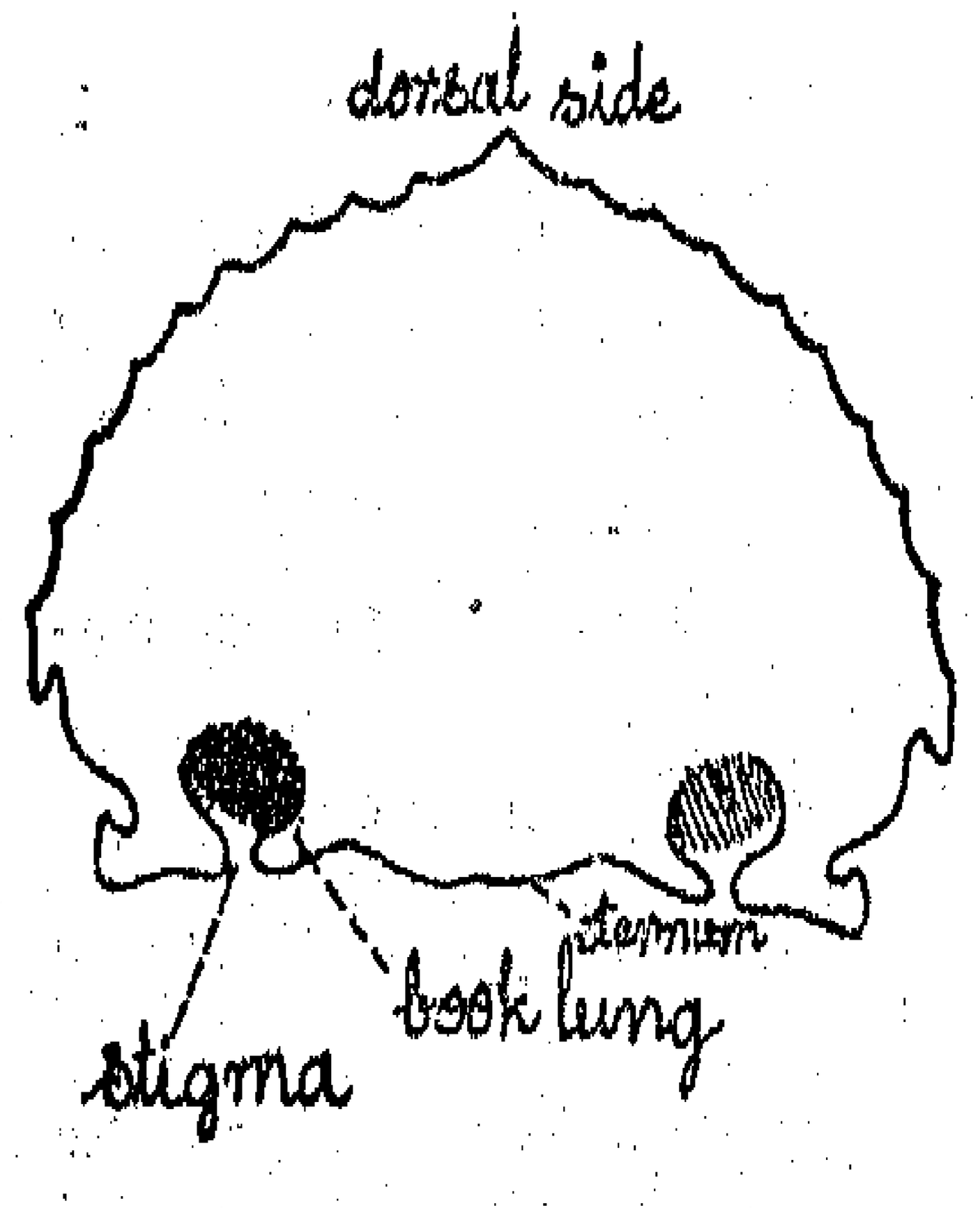

Fig. 272. Diagram showing the position of book lungs in a cross section through mesosoma.

relaxation of the cavity of the book-lung, the air being forced by compression of the pulmonary sac out through the stigma and drawn into the pulmonary sac through the stigma when the muscles relax and the pulmonary sac resumes its full size; the air drawn afresh is passed between the laminae and oxygenates the blood by diffusion. There is however no doubt in the fact that respiration does occur by diffusion. It is stated that the air in the pulmonary sac is moistened by the secretion of certain cells found at the free end of the laminae; the humid air suffers the respiratory exchange much more easily. The book-lungs get their supply of venous blood from the ventral sinus through a diverticulum which enters the lamellae at their base. The oxygenated blood of the book-lungs is collected by a pulmonary vein which opens into the pericardium. Thus the four pairs of book lungs act as the main respiratory organs of the scorpions which leads a terrestrial life. There is no trace of *tracheae* in scorpions and this distinguishes their mode of respiration from most of the other arthropods.

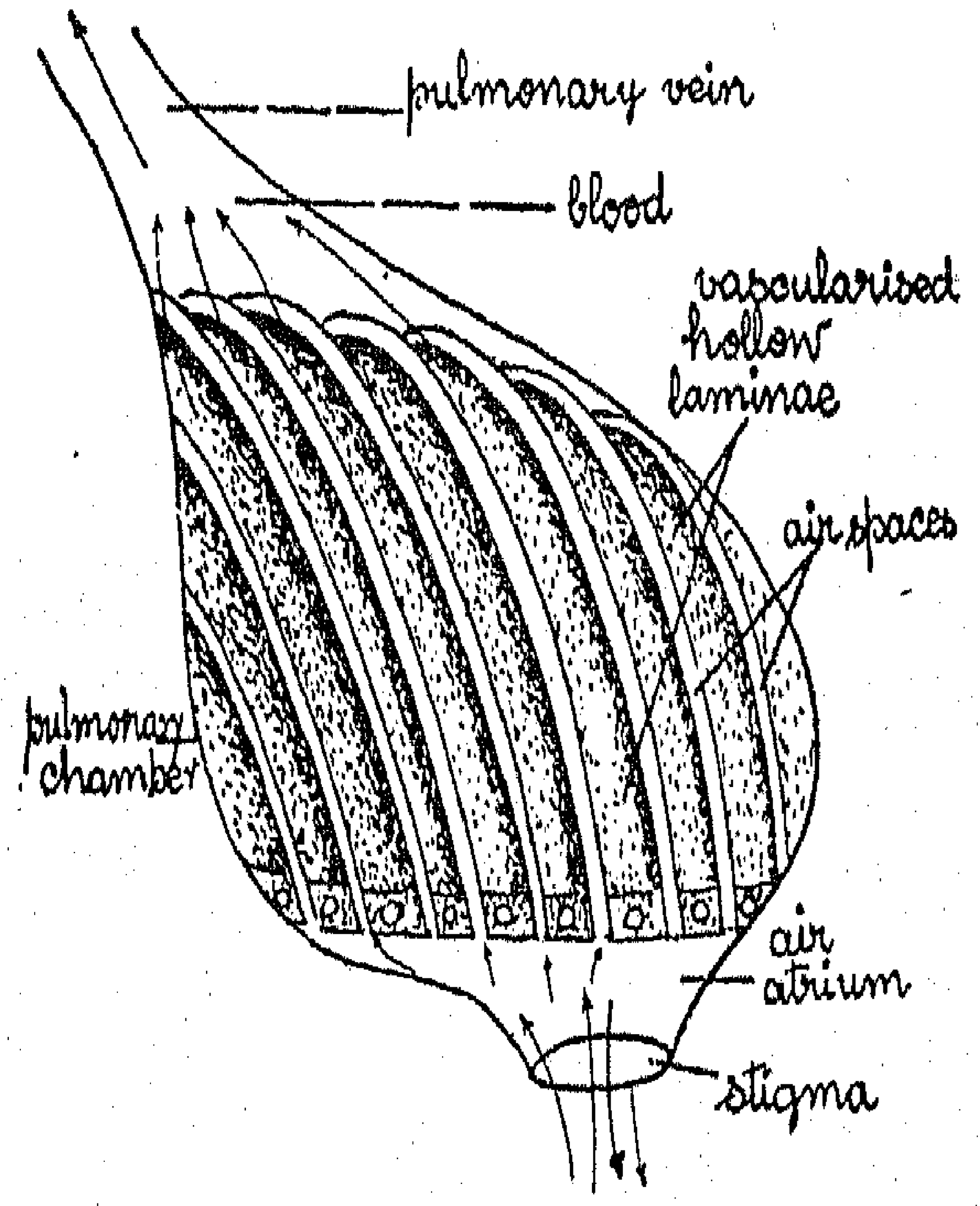

Fig. 273. Section of a book-lung to explain the structure (Diagrammatic).

Reproductive system: The *males* and *females* are separate.

The **male** has a pair of longitudinal tubular testes each lying in the last five mesosomatic segments. In each testis, the two longitudinal tubes are connected by cross branches. From the outer angle of the anterior most side of the testes arise the vasa deferentia, one on either side. Distally each *vas deferens* dilates to form an *ampulla*. A club shaped *vesicula seminalis* opens at the terminal part of the ampulla; the vesicula seminalis is full of mature spermatozoa. (Matured spermatozoa travelling through the vasa deferentia reach the vesicula seminalis). There is a *cylindrical gland* on each side which also opens into the ampulla. The *oval gland* lies on the inner side and opens into the genital chamber. One genital chamber lies on either side and each has in its base a backwardly directed *paraxial organ* within which is found a tightly fitting chitinous rod known as *flagellum*. Probably the flagella are everted out through the male genital pore during copulation, the two everted flagella forming the '*double penis*' of the scorpion. The cylindrical gland and the oval gland are the accessory glands. The two genital chambers (ejaculatory organs) form a *common chamber* in the median line and this opens to the exterior by a genital aperture just behind the genital operculum (See fig. 274).

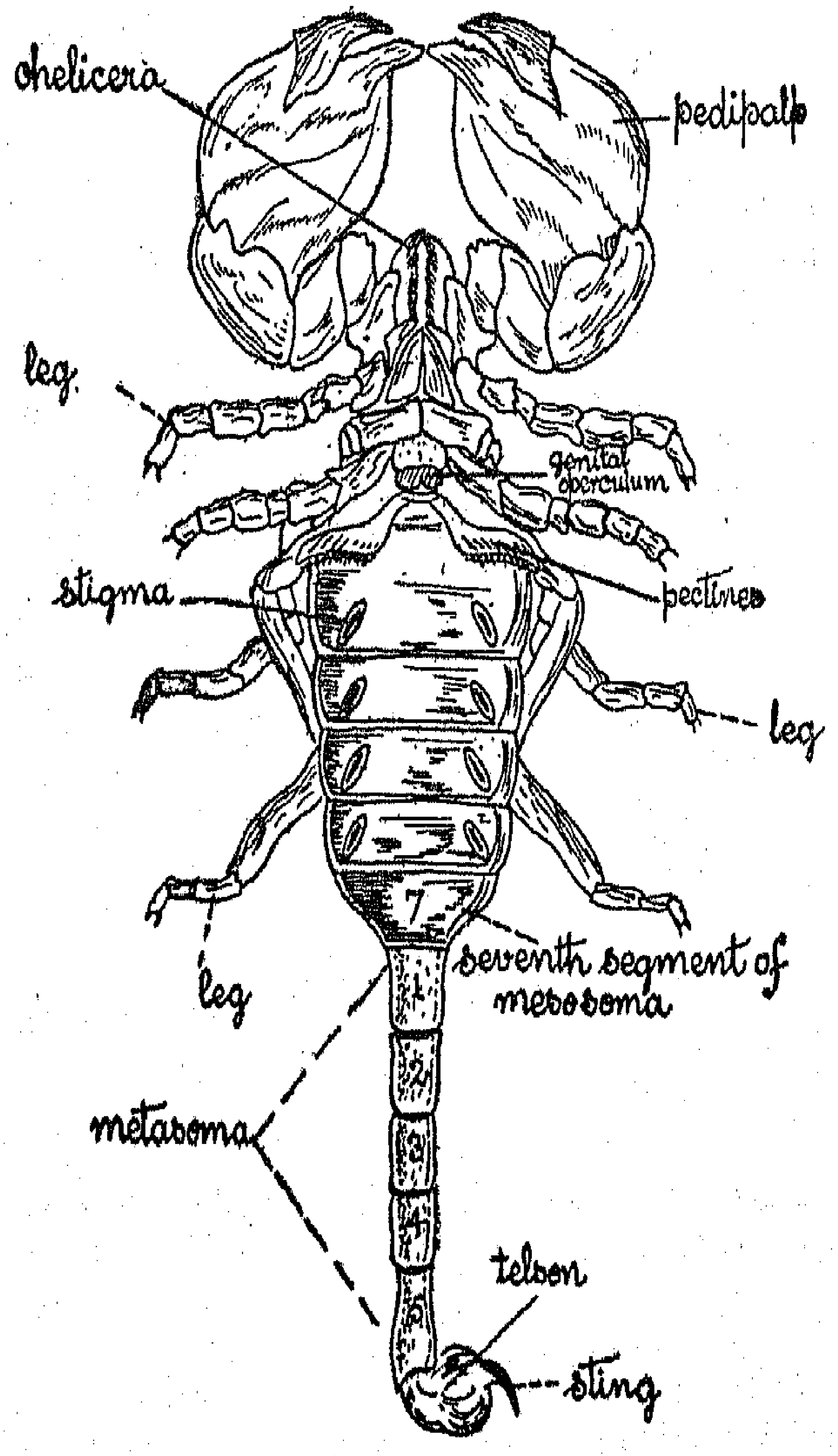

Fig. 274. Ventral view of the scorpion.

The **ovary** in the **female** is unpaired, consisting of three longitudinal tubules with transverse connecting branches. From the ovarian tubules many *diverticula* arise in which the developing

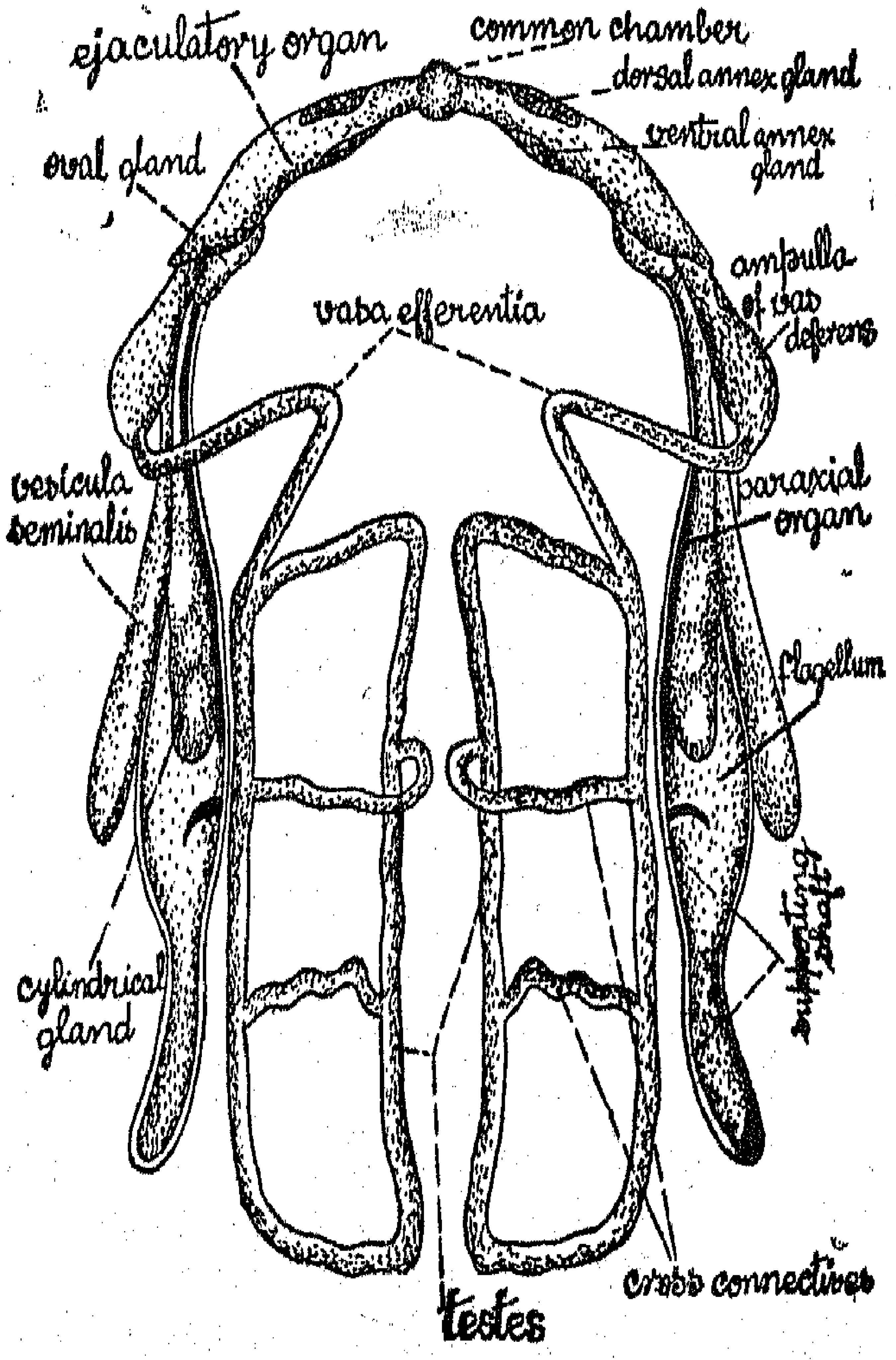

Fig. 275. Male reproductive organs of Scorpion (Palamnaeus).

embryos are accommodated. The side tubules are very much longer than the median which lies below the gut. The ovary lies in the mesosoma of the female in the last five mesosomatic segments. The developing ova find shelter for further development inside the follicles or diverticula already described. The right and the left ovarian tubes run anteriorly as the two oviducts which unite in the *median genital chamber*. The median genital chamber opens to the exterior by the female genital aperture lying just beneath the genital operculum on the first segment of the mesosoma. Fertilization occurs in the follicle or in the oviduct. The scorpions are viviparous.

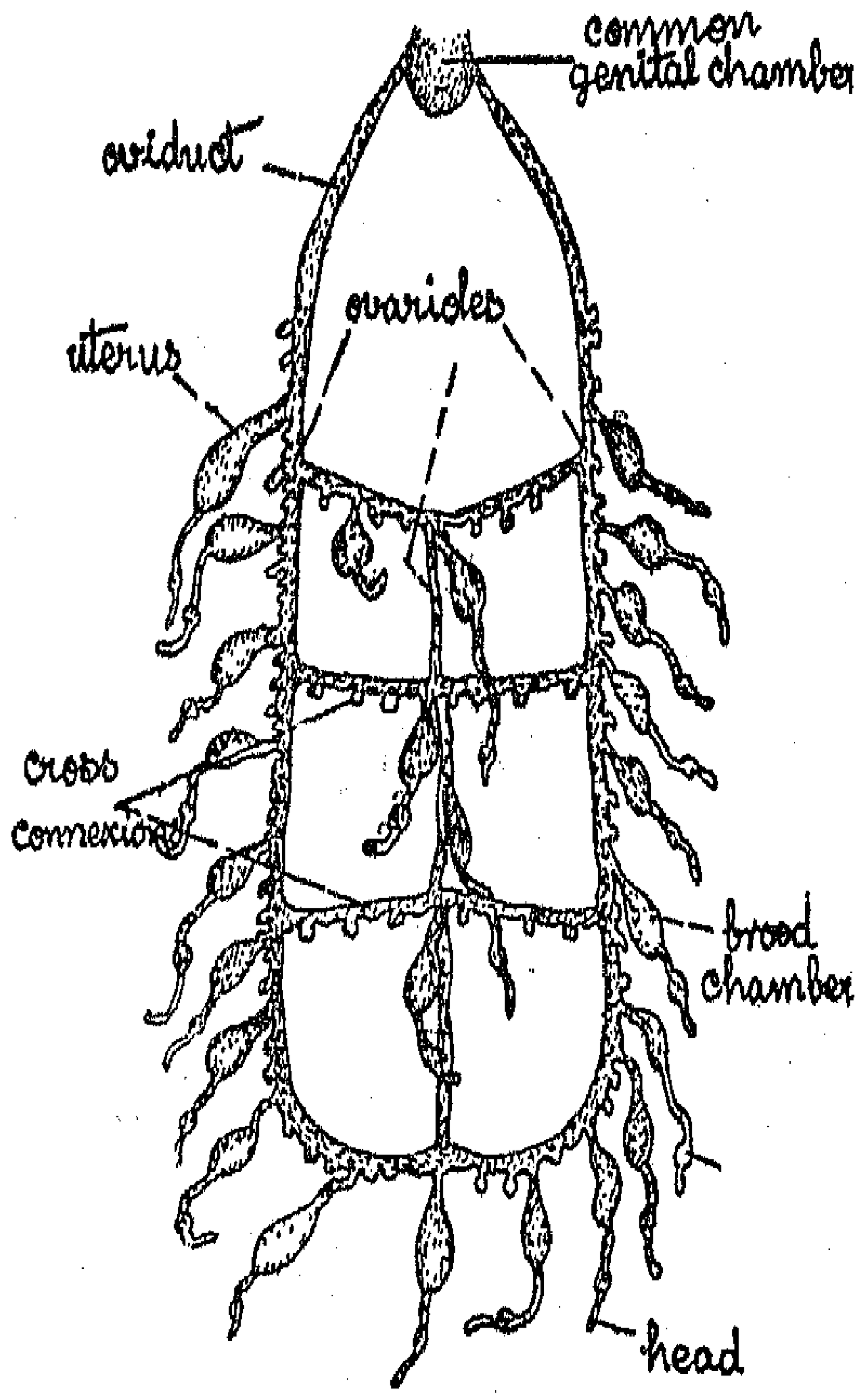

Fig. 276. Female reproductive organs Palamnaeus.

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Some Arthropod Types

[In this chapter we will briefly describe *Lepas*, *Sacculina*, *Eupagurus* (Hermit crab), *Lepisma*, *Termites* and *Xenopsylla* etc.]

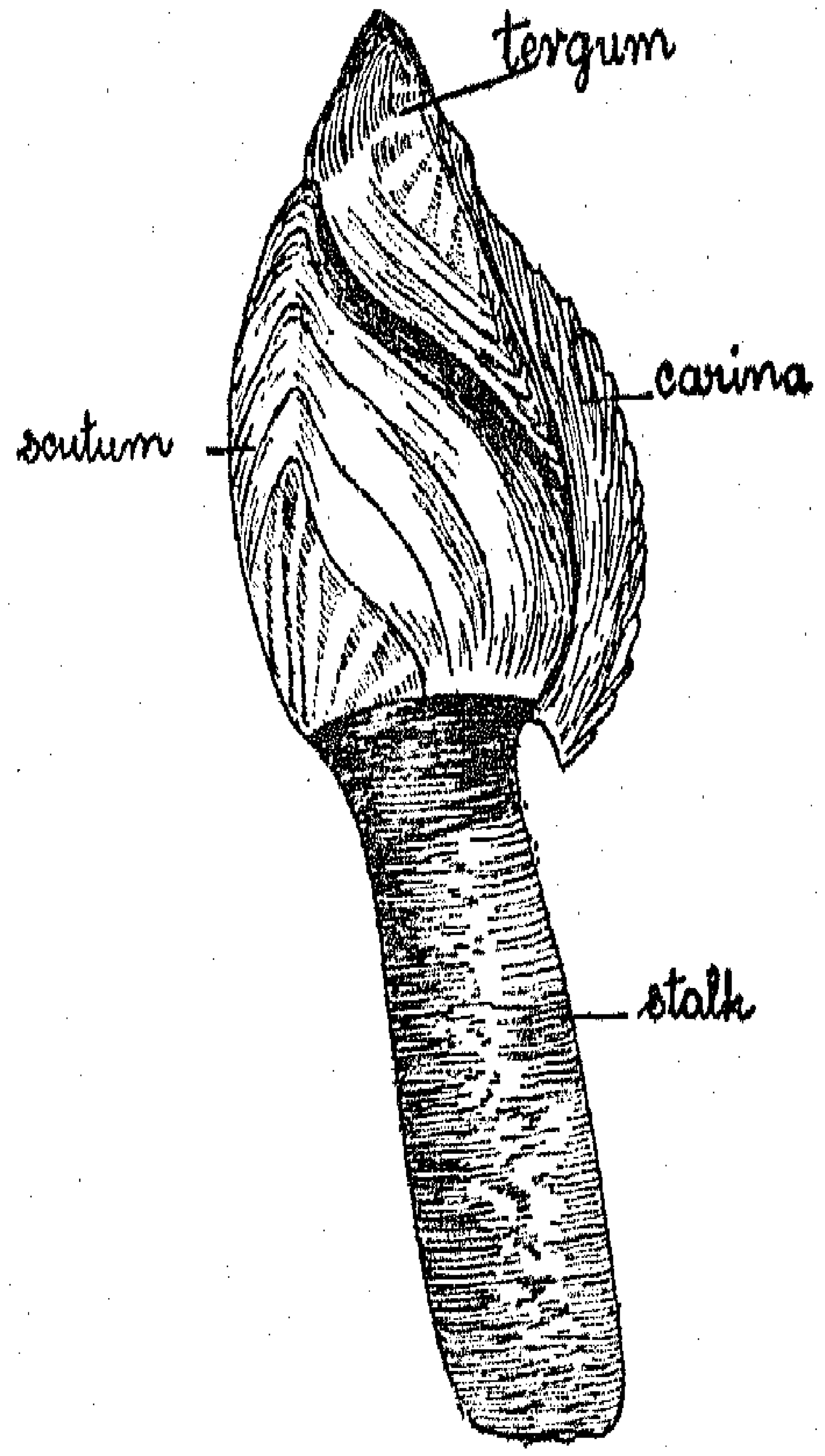

Fig. 277. Lepas anatifera (After Darwin).

1. *Lepas* [(The common goose-barnacle) Phylum **Arthropoda**, class **Crustacea**. Subclass **Cirripedia**, Order **Thoracia**] is marine, keeps hanging by a stalk or *peduncle* which represents the anterior most part of the head which has elongated and which bears vestiges of antennules, imbedded in a cement by which it is held fast: The long *stalk* is used for attachment, at its distal end it bears the body proper enclosed in a fold of skin which is hardened by five calcareous plates to form a sort of bivalve shell; the median dorsal plate is the *carina*, the two lateral and proximal plates are the *scuta*, and the two lateral and distal ones are the *terga*. The antennae are absent. The youngone is a *nauplius*→*cypris stage* (with body enclosed in a bivalve shell)→the adult.

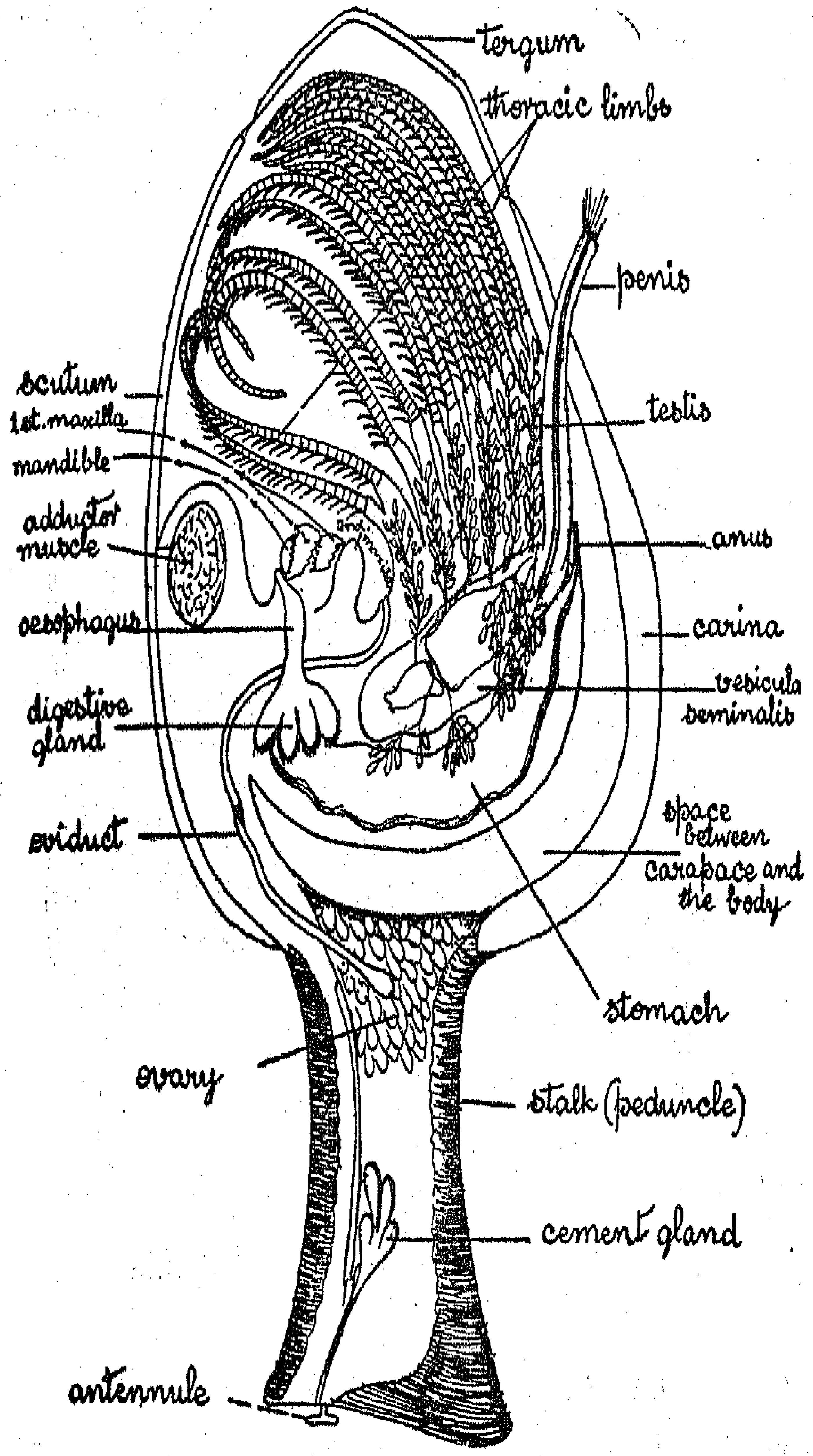

Fig. 278. Lepas anatifera, anatomy (After Shipley and Macbride).

2. *Sacculina* [Phylum **Arthropoda**, class **Crustacea**, Subclass **Cirripedia**, Order **Rhizocephala**[1]] *Sacculina* is a parasite on crabs. The adult *Sacculina* looks like a tumour on the abdomen of its host for *Sacculina* has no appendages, no mouth, no anus and nor any trace of segmentation. From the attached end of this 'tumour-like' parasite fungus like filamentous roots penetrate the body of the host and absorb nutriment for itself. *Sacculina* offers a remarkable example of extreme degeneration

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[1] [Rhizocephala, parasitic on decapod crustaceans, body extremely degenerated, no alimentary canal at any stage, no appendages in the adult; fungus-like roots from their body permeate the body of the host *Sacculina*.]

of the adult due to parasitic life. The adult *Sacculina* cannot be recognised as a crustacean and it is only by reference to its life history which shows the *nauplius* and the *cypris* larval stages that it is identified as a crustacean. The parasite *Sacculina* also exerts a powerful effect upon its host, the crab, bringing about changes in its secondary sexual characters. The male crab (infested by *Sacculina*) develops the female secondary sexual characters. The gonads in the male get degenerated and often the crab is killed. Such a castration of the host due to the influence of a parasite as exhibited by the crab is known as **parasitic castration** and is probably due to the parasite's influence on and interference with the matabolism and hormone physiology of the host.

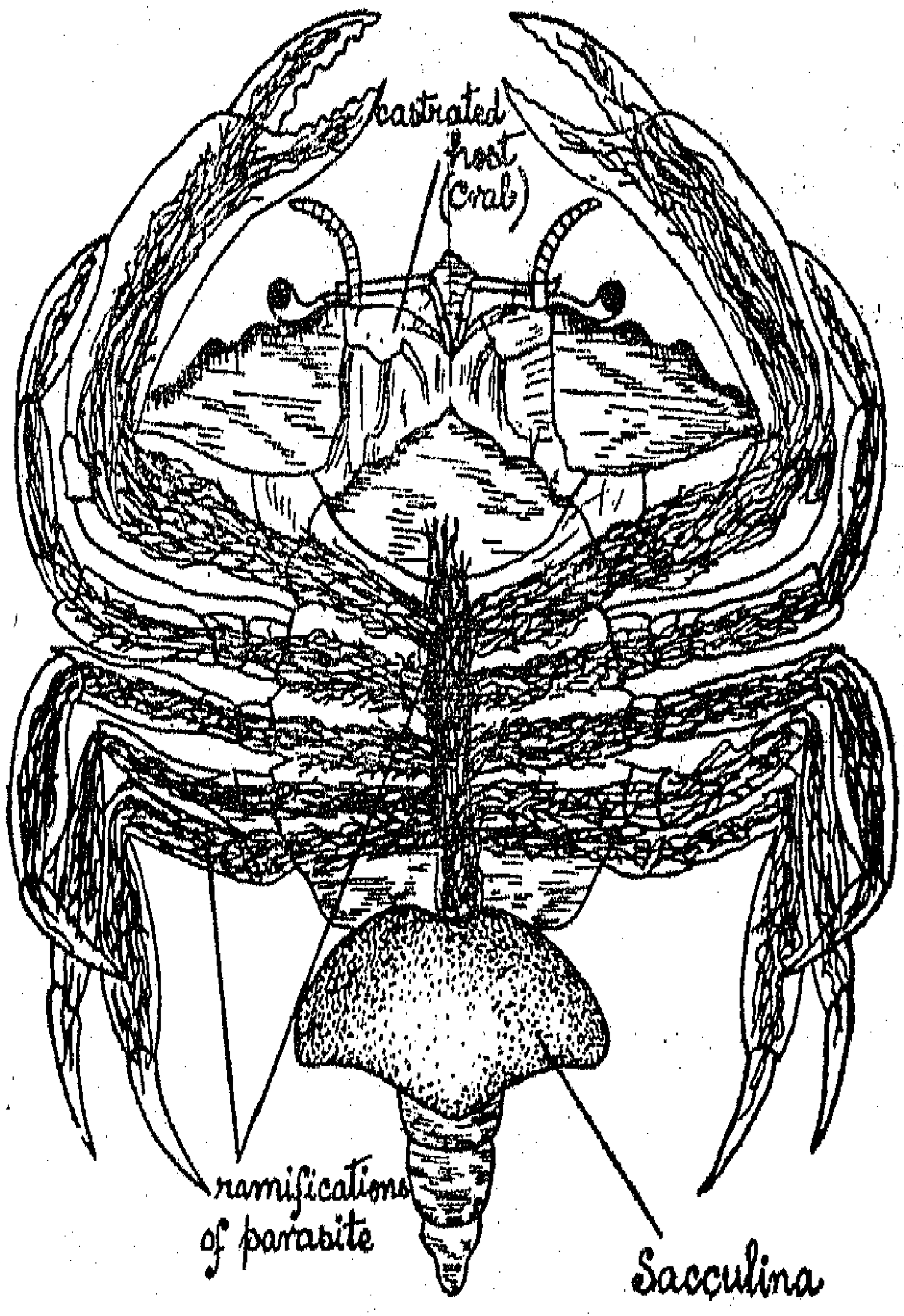

Fig. 279. Sacculina carcini on abdomen of crab.

3. *Eupagurus* [**Arthropoda**, Class **Crustacea**, Subclass **Malacostraca** Order **Eucarida**, Suborder **Decapoda**, Section **Anomura**].

Eupagurus (Hermit crab) inhabits the empty shells of the gastropod molluscs. The sharply twisted abdomen is completely enclosed within the shell while the cephalothorax protrudes out.

The abdominal appendages are atrophied. The two uropods are however present and serve to maintain a hold on the molluscan shell. One of the chelate legs is greatly enlarged and its chela serves to close the mouth of the shell when the animal completely retracts within the shell. Both the chelate legs of the first pair may be enlarged and serve this purpose. The hermit-crab is said to kill the gastropod animal of the shell and remove its body bit by bit and thus get the shell evacuated for its own use.

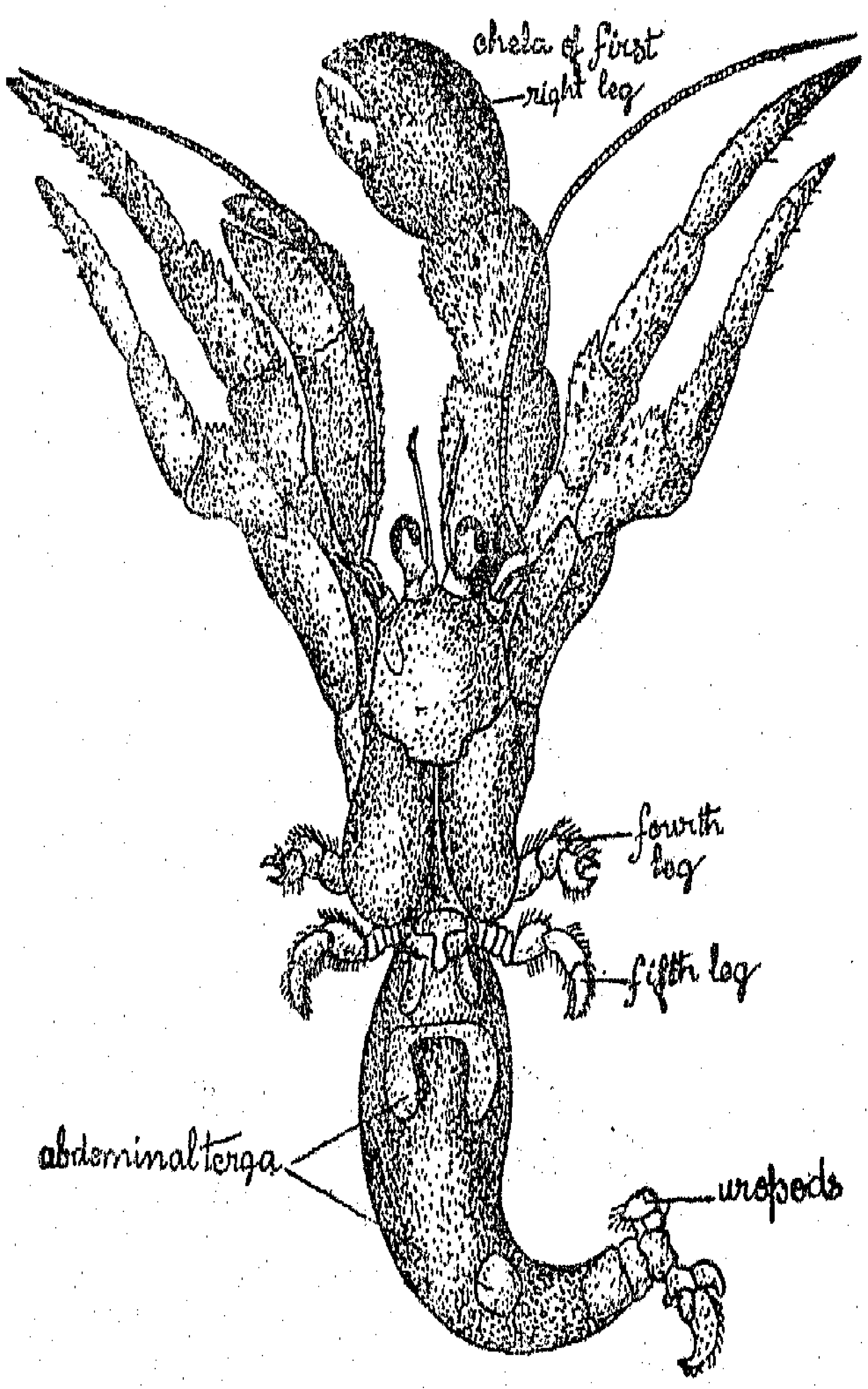

Fig. 280. Eupagurus bernhardus (After Bell).

4. *Lepisma* [**Arthropoda**, Class **Insecta** Subclass **Apterygota**[1] Order **Thysanura**[2]] *Lepisma* (Silver-fish) is very common

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[1] [**Apterygota**, wing-less insects, with slight or no metamorphosis.]

[2] [**Thysanura**, small sized insects with compound eyes; long abdomen with eleven segments, eleventh segment forms a median tail-filament; cerci are long. Malpighian tubules present. Antennae are long. Mouth parts adapted for biting; long ovipositor: segmental protrusible vesicles and styles present. Tarsi have 2 to 4 segments.]

in human dwellings; it is often found in books and other papers, files etc. kept at a place for a long time. The insect is pearly-white in colour, about an inch or a little less in size and looks like a very small 'fish'. The body is covered with scales. There are no wings.

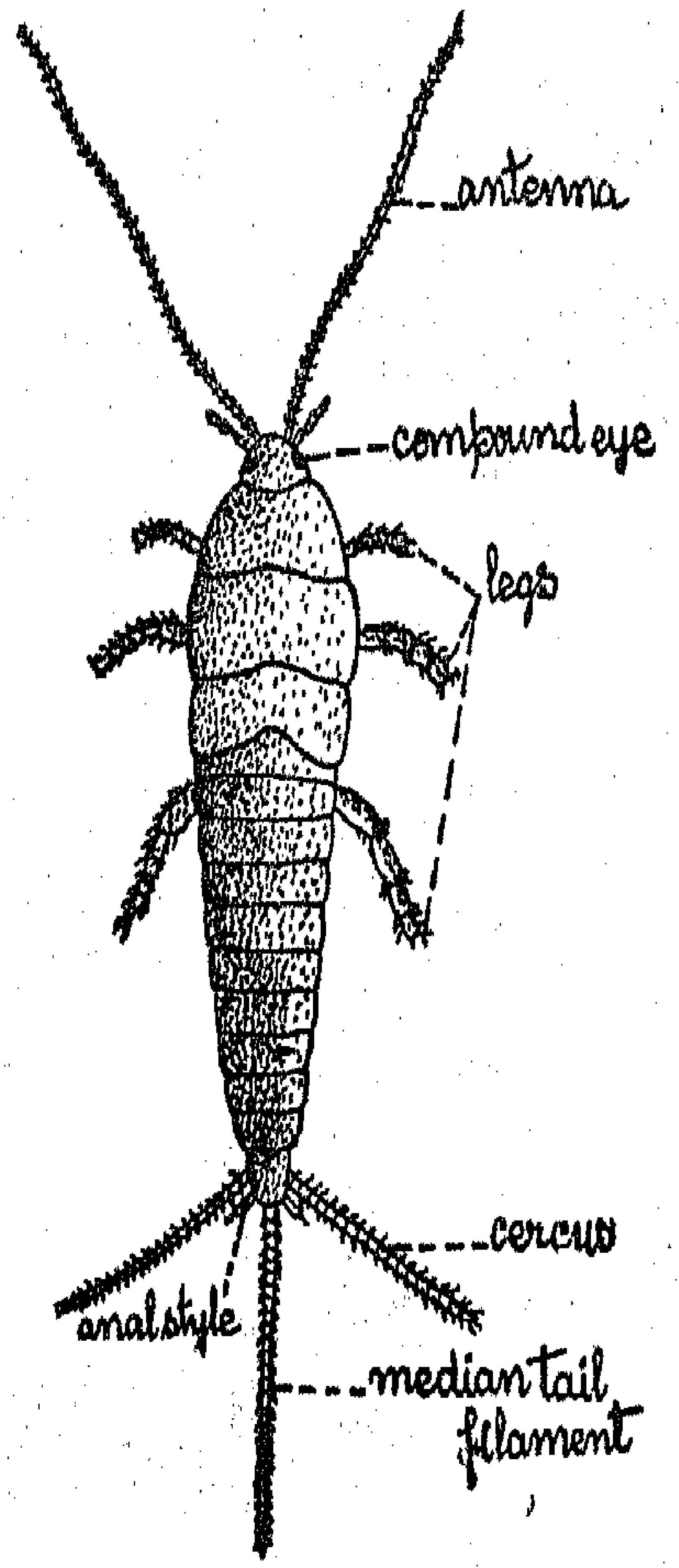
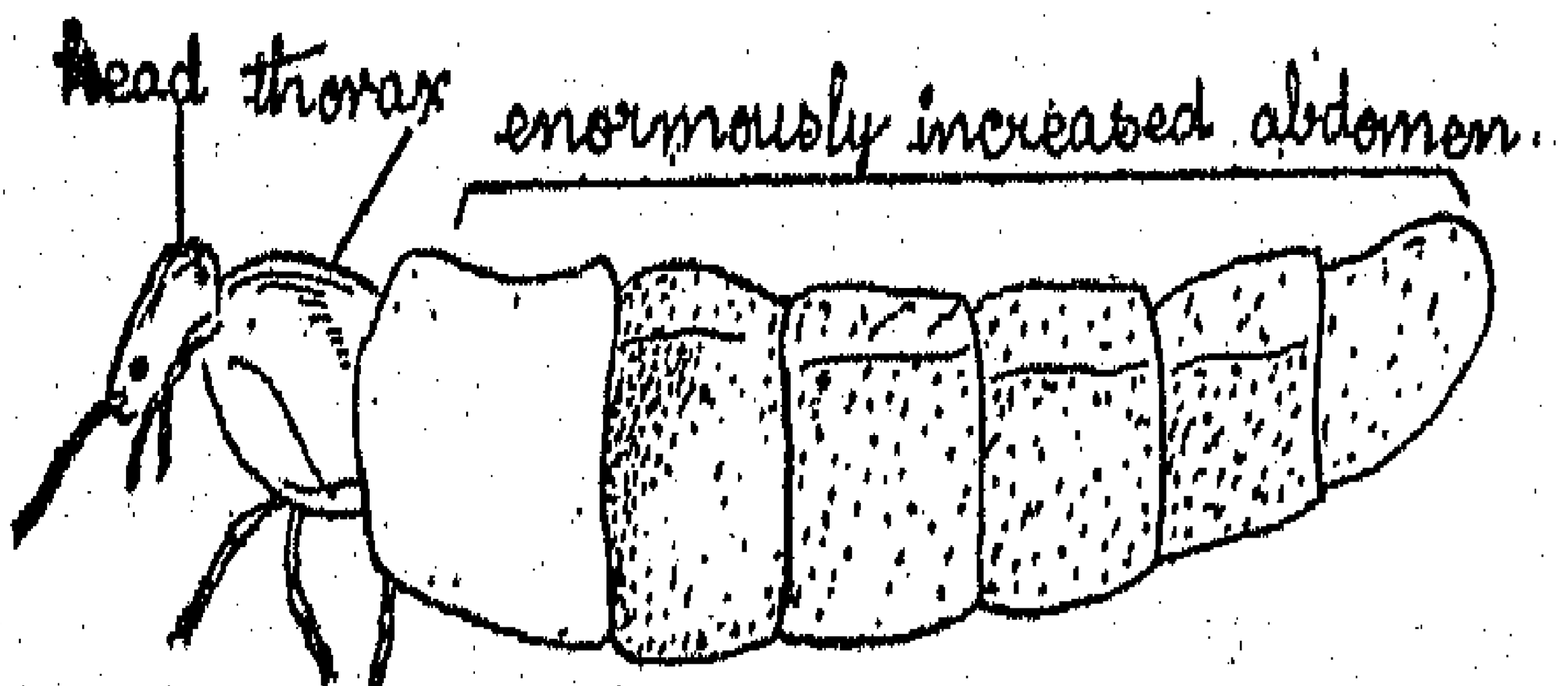


Fig. 281. Lepisma (silver fish).

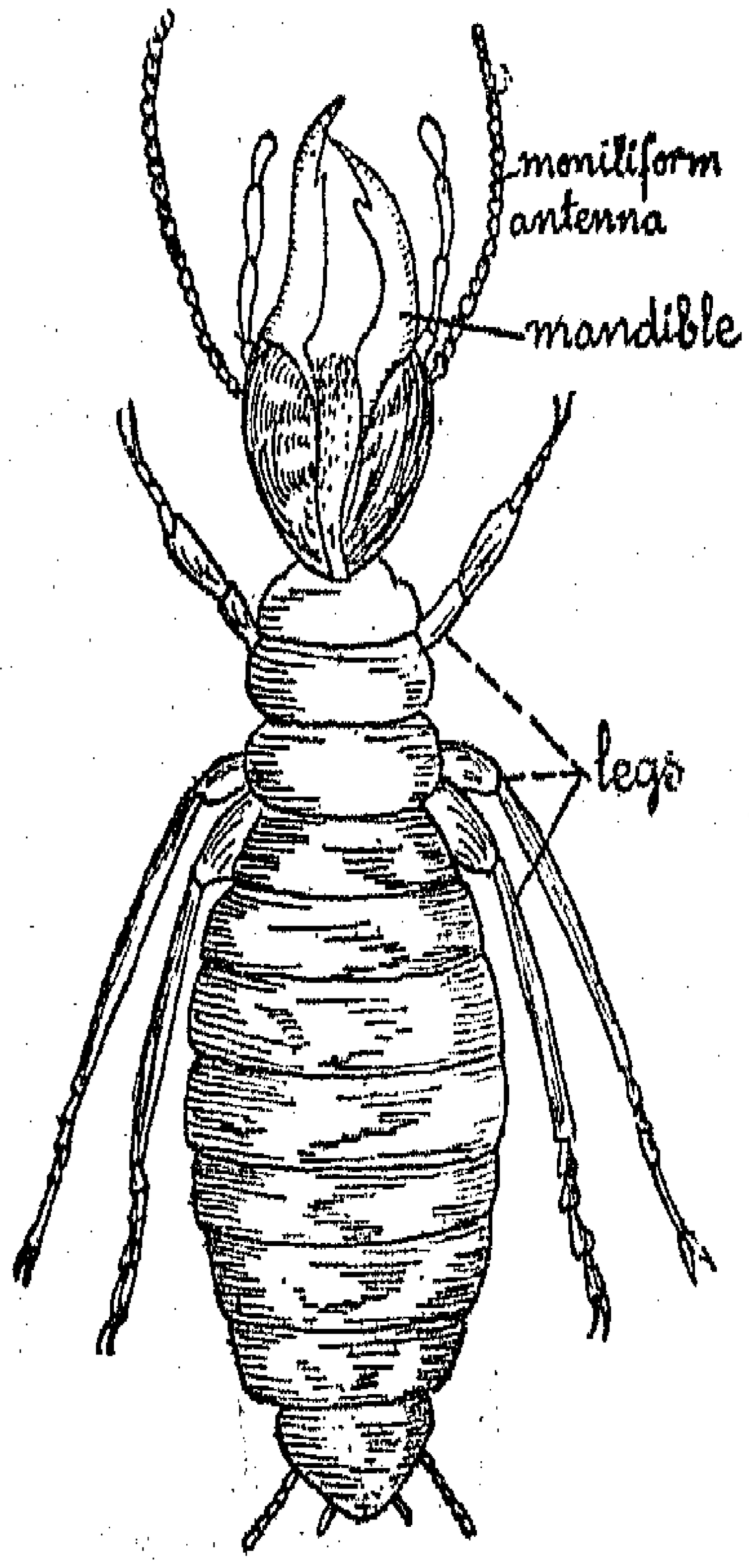
5. Termites or *'White ants,* **Arthropoda**, Class **Insecta** Sub-class **Petrygota**, Division **Exopterygota**, Order **Isoptera**] The



Abdomen is very large due to increased development of ovaries and fat body; legs are very small; is incapable of movement; is fed by workers and defended by soldiers.
She lives in a special royal chamber of the termitarium.
The size is 5 to 9 cms. or may be even more.
It lays one egg per second; is an inert egg laying machine

Fig. 282. The queen (Cyclotermes sp).

Isoptera are *social insects* exhibiting polymorphism; they are of a pale colour and live in large communities. Two pairs of very similar elongate and membranous wings superposed flat on the back during the rest; the wings are shed by means of fractures at the base. *Tarsi* four jointed, *cerci* very short, *ligula* four-lobed, *genitalia* rudimentary or absent.



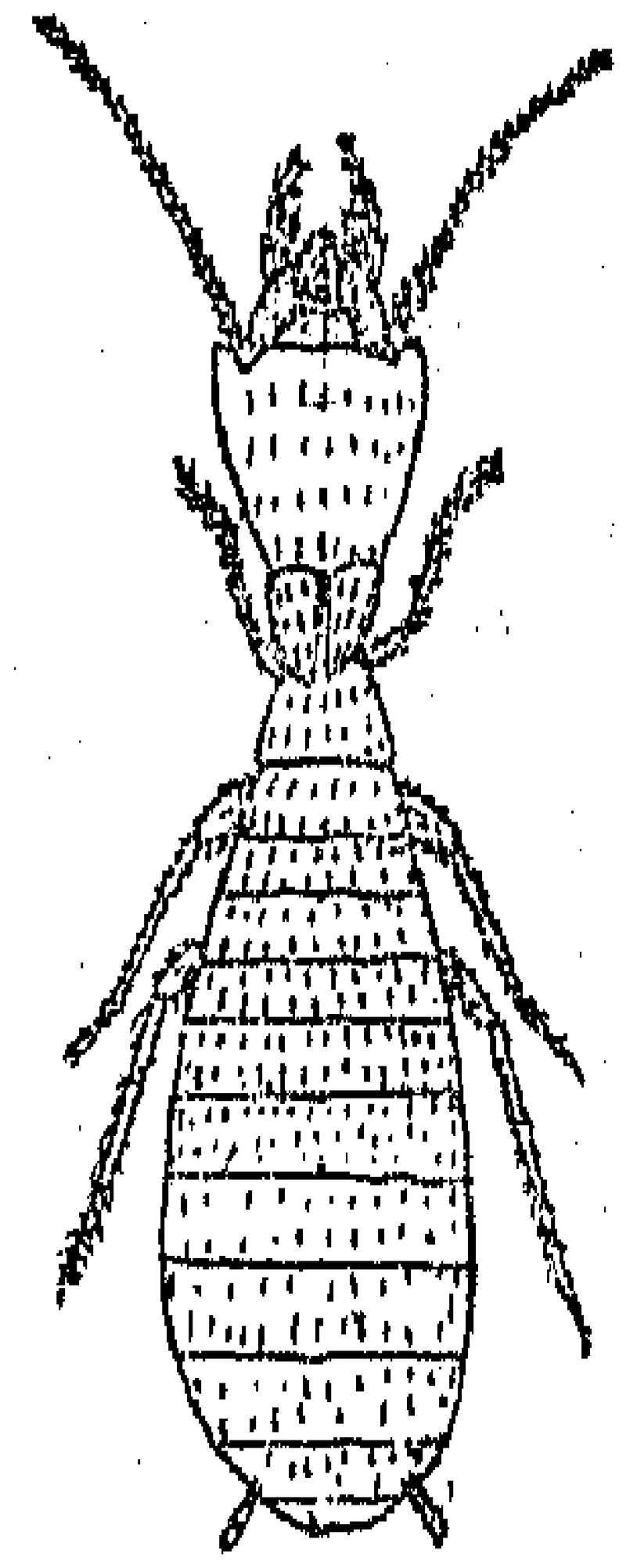


Fig. 283. Termite worker.

Fig. 284. A termite soldier.

The termites lead a social life and their large organized colonies reside in the *nests* known as *termitaria.* They make tunnels in wood or special large nests built out of a mixture of wood, earth and their faeces cemented together by saliva. *Archotermopsis* and *Termopsis* inhabit moist decaying trunks and logs of wood; their abodes are a series of galleries excavated in the wood which cannot be seen from the outside. *Mastotermes, Calotermes, Neotermes* and *Cryptotermes* bore into dry wood and furniture etc. *Calotermes militalis* burrows in the stems of bushes of tea and does much harm to the yield of tea in Ceylon.

There are *three castes* of reproductive forms and *two castes* of steriles forms; thus **in all there are five castes in a termite social unit.**

1. The *Macropterous forms* possess two pairs of large membranous wings of nearly equal size, well developed compound eyes and paired ocelli; large brain and well developed gonads. They are adapted for a brief aerial life and they lay foundation of fresh colonies. From them arise both fertile and sterile forms.
2. *Brachypterous forms* wings vestigial, scale like, subterranean

habit, compound eyes, brain, sexual organs somewhat reduced. Their role is uncertain. 3. *Apterous forms* lack wings altogether, are subterranean, possess vestigial compound eyes and lack pigment in their cuticle. The fertilized females grow enormously, the ovaries and fat body grow out of proportion and occupy the major space in 'immense' abdomen. The queen is exclusively nourished upon the saliva and is fed and taken care of by the workers. The queen does not ingest hard wood. In the queen 'the reproductive system monopolizes' and the queen becomes converted into one vast, inert egg-laying mechanism. The queen may lay a million eggs a year.

The *Sterile Castes* consist of individuals in which the sexual organs atrophy and are nonfunctional : examples are 4. *workers* and 5. *soldiers*. The *workers* lack external sexual characters, are pale coloured, head points downwards, compound eyes wanting or vestigial. The mandibles of workers are powerful in adaptation to the gnawing of wood and other vegetable tissue. The workers take care of eggs, of youngones, feed the queen, collect and store food and cultivate fungi in special 'rooms' and are the most notorious destroyers of wood work and crops etc. 5. *Soldiers* have a large chitinized head and very large mandibles. The soldiers are responsible for defence of the colony which they perform due to their powerful mandibles and their capacity to eject an offensive fluid upon the attackers.

6. *Pediculus humanus* [Phylum-Arthropoda, class-Insecta, Division Exopterygota, Order-Siphunculata] Siphunculata include blood sucking parasites of mammals, also known as sucking lice : they lack wings, piercing and sucking mouth parts present, tarsi are one segmented, claws are single, no metamorphosis, are ectoparasites on mammals. *Pediculus humanus* the common body louse of man transmits typhus and relapsing fever and many other diseases in man. It lays eggs which become attached to the hair of man or his clothes. A single louse lays about ten eggs per day and in all about 300 eggs. The life-cycle is completed in three weeks to a month.

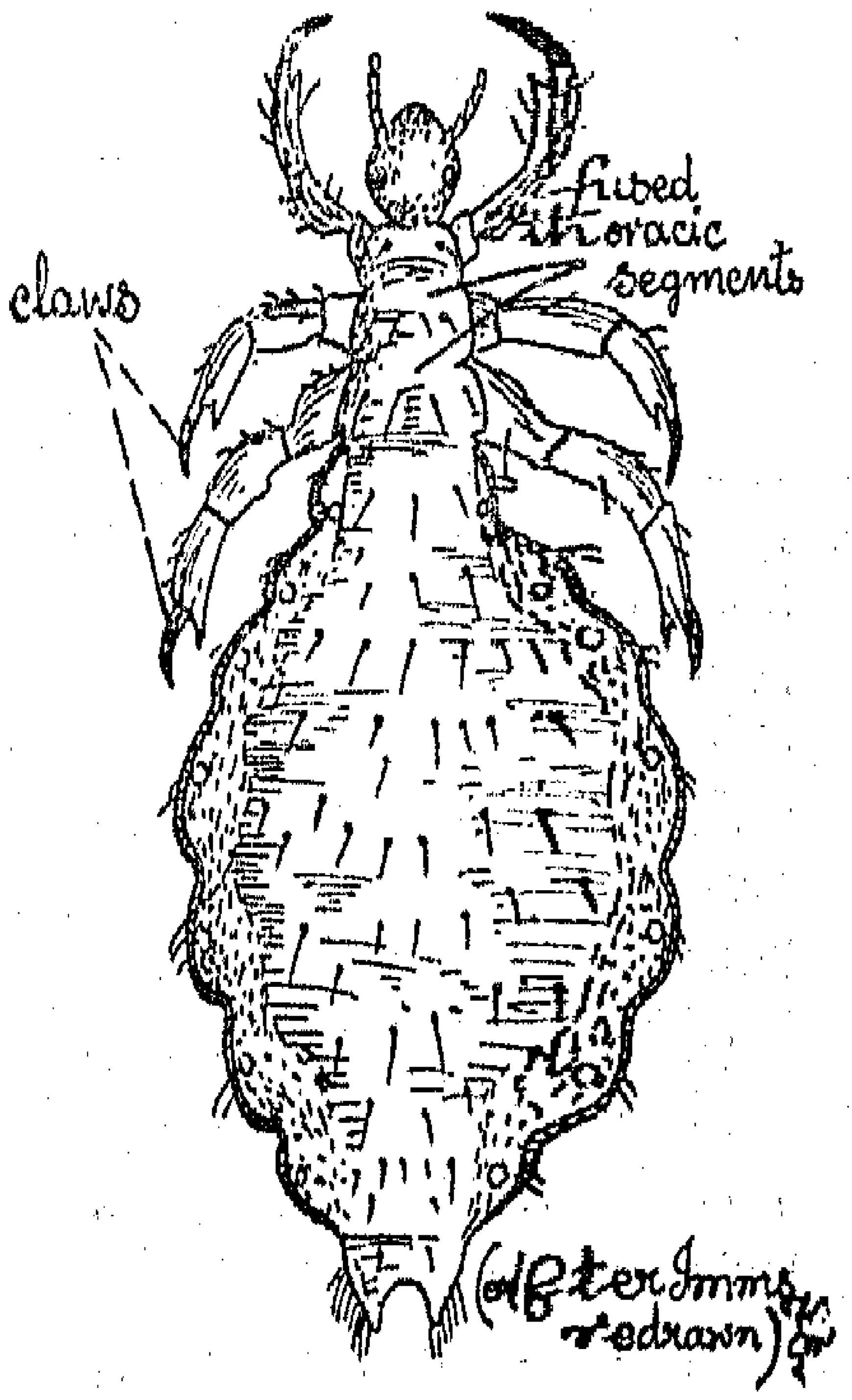


Fig. 285. Pediculus humanus (After Imms).

7. *Dysdercus* [class-Insecta, order Hemiptera, Suborder Heteroptera which are terrestrial, vegetarian or predators and blood suckers]. *Dysdercus*, the cotton stainers of the tropics ; they feed on cotton bolls into which they inject a micro-organism due to which a red stain develops on the cotton fibre. *Cimex*, the common bed bug, an ectoparasite having vestigial wings, a flattened body and prominent claws. *Cimex is* a much hated inhabitant of human dwellings,—an obnoxious creature with considerable capacity of survival without meals and hence rendering its eradication difficult after having established once. It is a notorious blood-sucker of man and quite often disturbs human sleep.

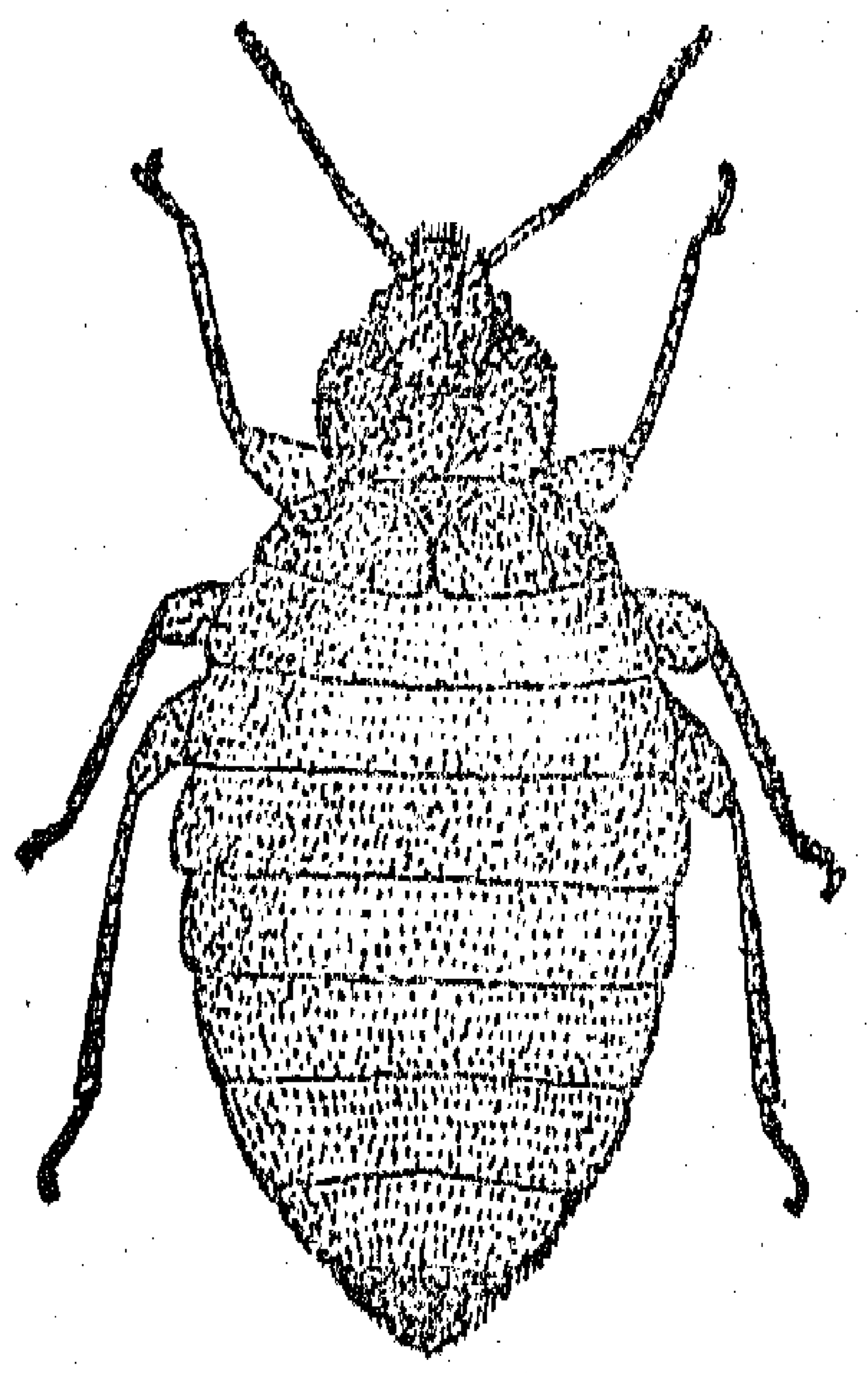


Fig. 286. Cimex sp

8. *Bombyx mori* (The silk moth) [Order Lepidoptera which includes butterflies and moth, these insects have plenty of scales, siphoning type of mouth parts (See page 296), two pairs of membranous wings clothed with scales ; complete metamorphosis occurs ; the *larvae* are phytophagous (plant eating). The wings of adults bear scales causing beautiful colour designs. The insects feed on honey, dew, over-ripe fruits and nectar of flowers. Their larvae eat leaves, roots, wood, seeds etc. The caterpillars damage crops.] The Silk Moth *Bombyx mori* is extremely beneficial to man for he owes silk to this insect. The insect originally belongs to China ; its larva is known as **'silk-worm'.**

The larva composes a *cocoon of silk* to protect itself and it is this cocoon which yields silk to man.

9. *Ants, bees, wasps* : [Order *Hymenoptera*—insects with membranous wings : the order is of considerable economic importance]. *Apis* (the honey bee) yields useful honey and wax. Parasitic hymenoptera are used in *biological control*[1] to eradicate many harmful insect pests. Carnivorous wasps (*Vespa*) devour other insect pests such as aphids. The parasitic hymenoptera are of great value to man for they check many plant-feeding insects. The larvae of ants, bees and wasps are legless. The ants, bees and wasps have an excellent social life and they have castes. The

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[1] *Biological control* is a method in which a particular insect is introduced by man to control another insect (which is injurious to crops etc.) and check its increase.].

workers are females which suppressed gonads; they are derived from fertilized eggs. The queens lay eggs and they are also derived from the fertilized eggs. The *males* or *drones* are produced from unfertilized eggs. *Vespa vulgaris, Vespa germanica* etc. are the wasps. The queen of *Apis mellifica* (Honey-bee) has an elongated abdomen and its main function is to lay eggs; it neither collects pollen, nor has wax and pharyngeal glands. A bee-hive may have as many as 80,000 bees majority of which are workers. The ants belong to the family *Formicoidea*; they are also polymorphic insects.

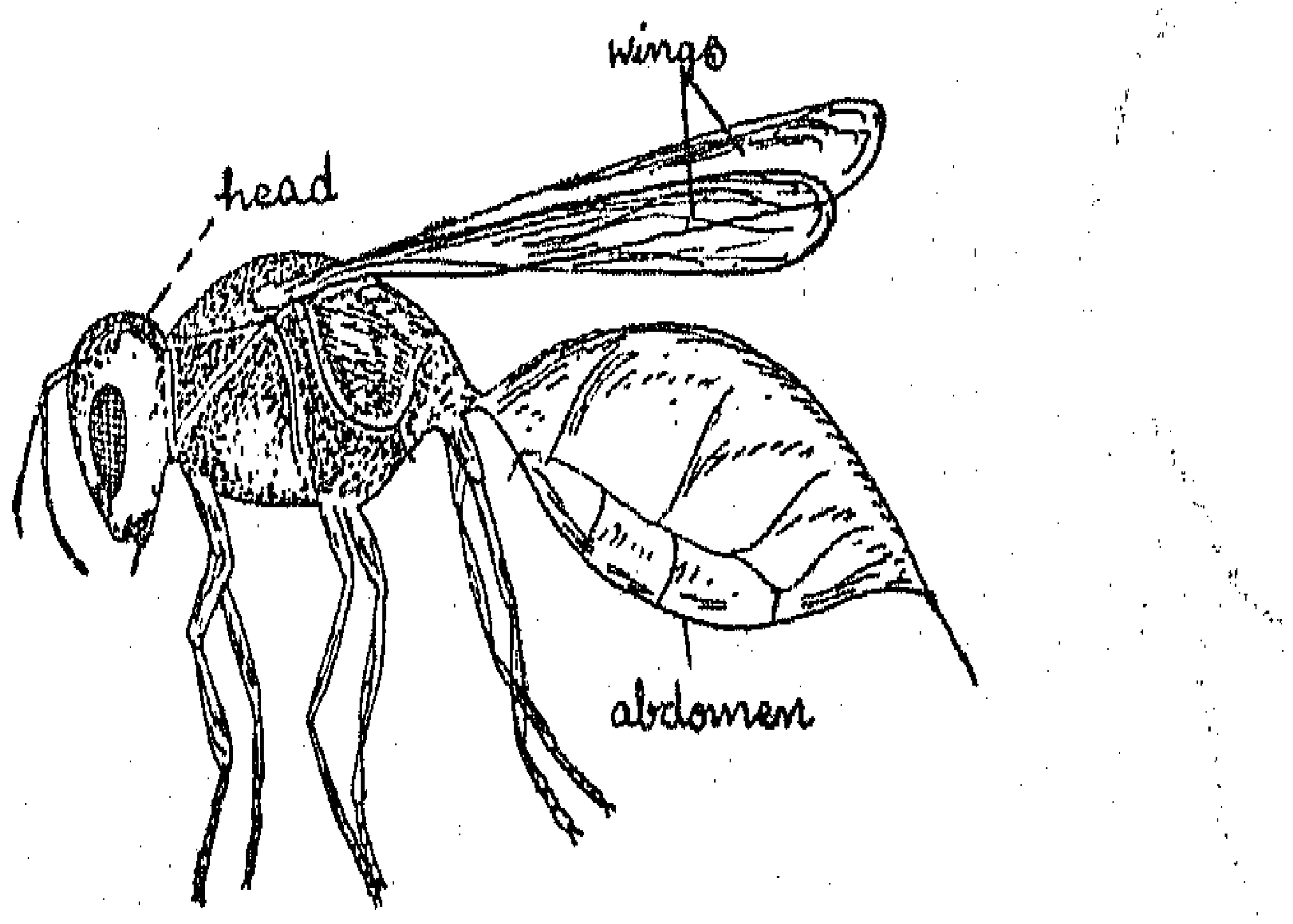

Fig. 287. A wasp.

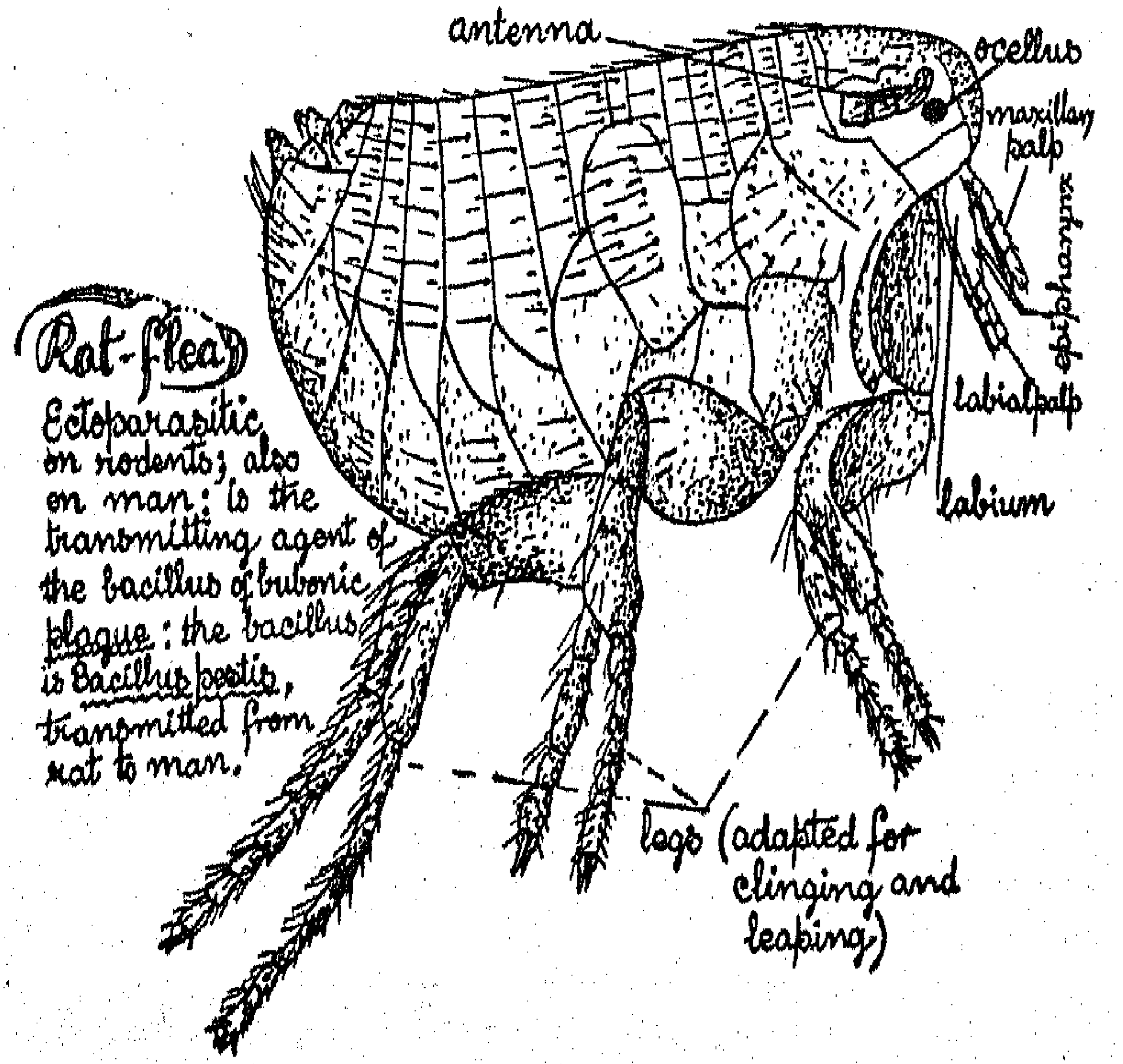
antenna
ocellus
maxillary palp
epipharynx
labial palp
labium
Rat-flea
Ectoparasitic on rodents; also on man: is the transmitting agent of the bacillus of bubonic plague: the bacillus is Bacillus pestis, transmitted from rat to man.
legs (adapted for clinging and leaping)

Fig. 288. Xenopsylla cheopis.

10. *Xenopsylla cheopis* (**Rat-flea**) [Class **Insecta**, subclass-pterygota Division-**Endopterygota**, Order **Siphonaptera** which includes fleas; *siphon*, a tube, *apteros*, without wings). The Siphonaptera include small insects without wings, adults are ectoparasitic on warm blooded animals, body laterally compressed, antennae short, piercing and sucking mouth parts, *larvae*: legless and vermiform, *pupae* protected by silk cocoons.]

Xenopsylla cheopis (the Rat-flea) transmits the bacillus of bubonic[1] plague from rat to man; the disease is found both in man and rodents (the order **Rodentia** under mammals with prominent incisor teeth and no canines e. g. squirrels, beavers, rabbits, rats and mice) probably the bacillus lives in the gut of the flea and the faeces deposited on the skin of the host find way into the wound due to scratching of the flea's bite. The eggs of the flea are usually found in the sleeping resorts of the hosts.

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[1] [*Bubonic*, accompanied by buboes, *bubo*=an inflammatory swelling of the glands esp. in the groin or arm pit.]

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Pila–Shell, Organs of Pallial Complex, Course of Water Current, Respiratory System and Adaptations to an Amphibious mode of Life, Veliger Larva

Pila globosa a common univalve mollusc is a fresh water form. [Mollusca class **Gastropoda**, Order **Prosobranchiata**, Example *Pila*]. The soft parts of the body of *Pila* are lodged in a shell formed of a single piece. The shell is of the form of an elongated hollow cone which is coiled round a central axis, the *columella*, the topmost tip is the *apex* of the shell and marks the first portion secreted. The shell has about 6½ *whorls* or *revolutions* which are in communication with each other. The last whorl containing the body is called the *body-whorl*; the rest of the shell is known as the *spire*. The spiral shell of *Pila* is *dextral*. The mouth of the shell can be covered by an *operculum*, a flat calcareous plate borne on the foot. The animal can retract the whole body inside the shell and then close the operculum to protect itself. The **shell** consists of an outer chitinous layer known as *periostracum* (formed of a horny substance conchiolin); beneath it is another calcareous layer, the ostracum beneath which is another layer called the *hypostracum* or the *nacreous*

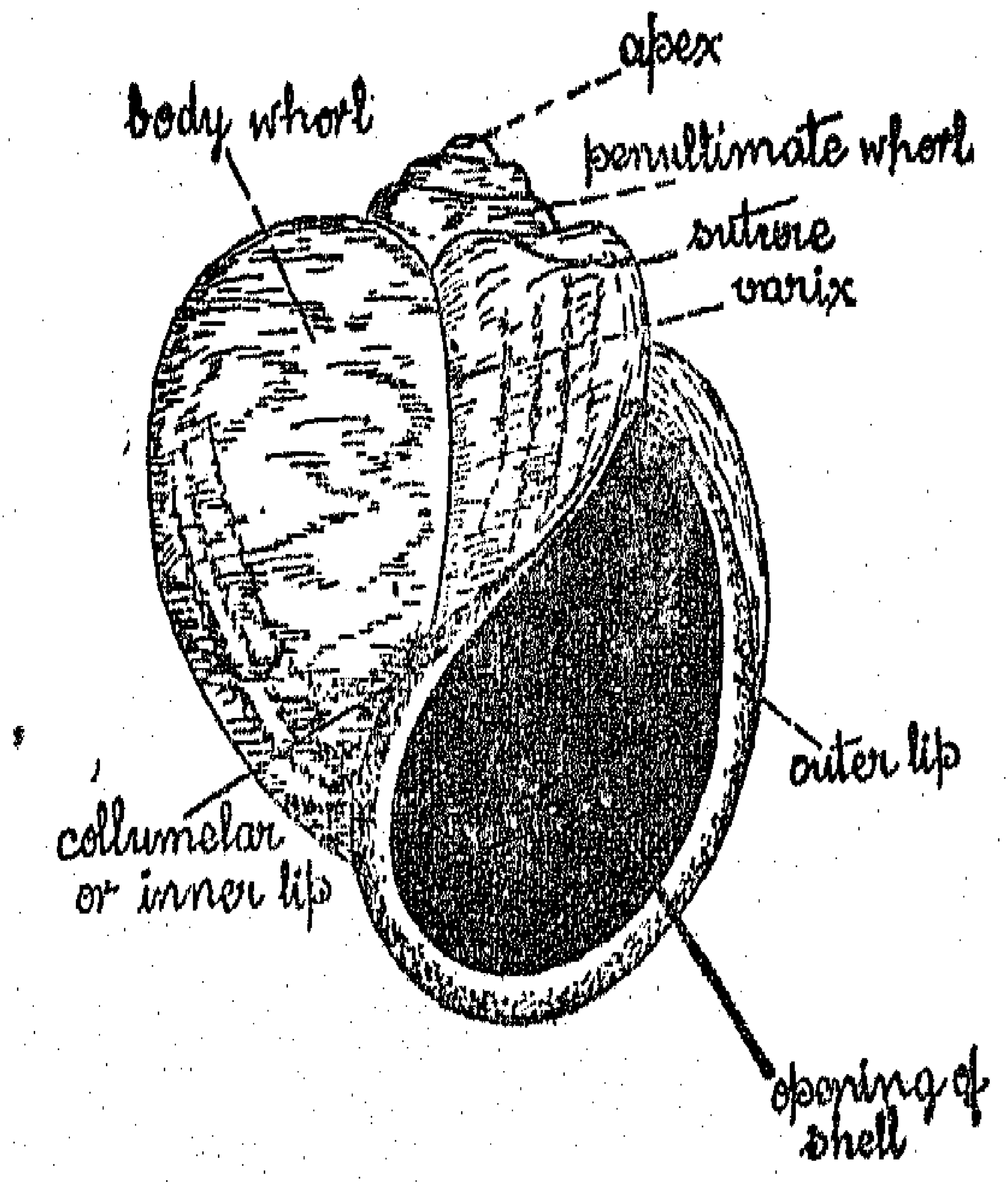

Fig. 289. Shell of Pila.

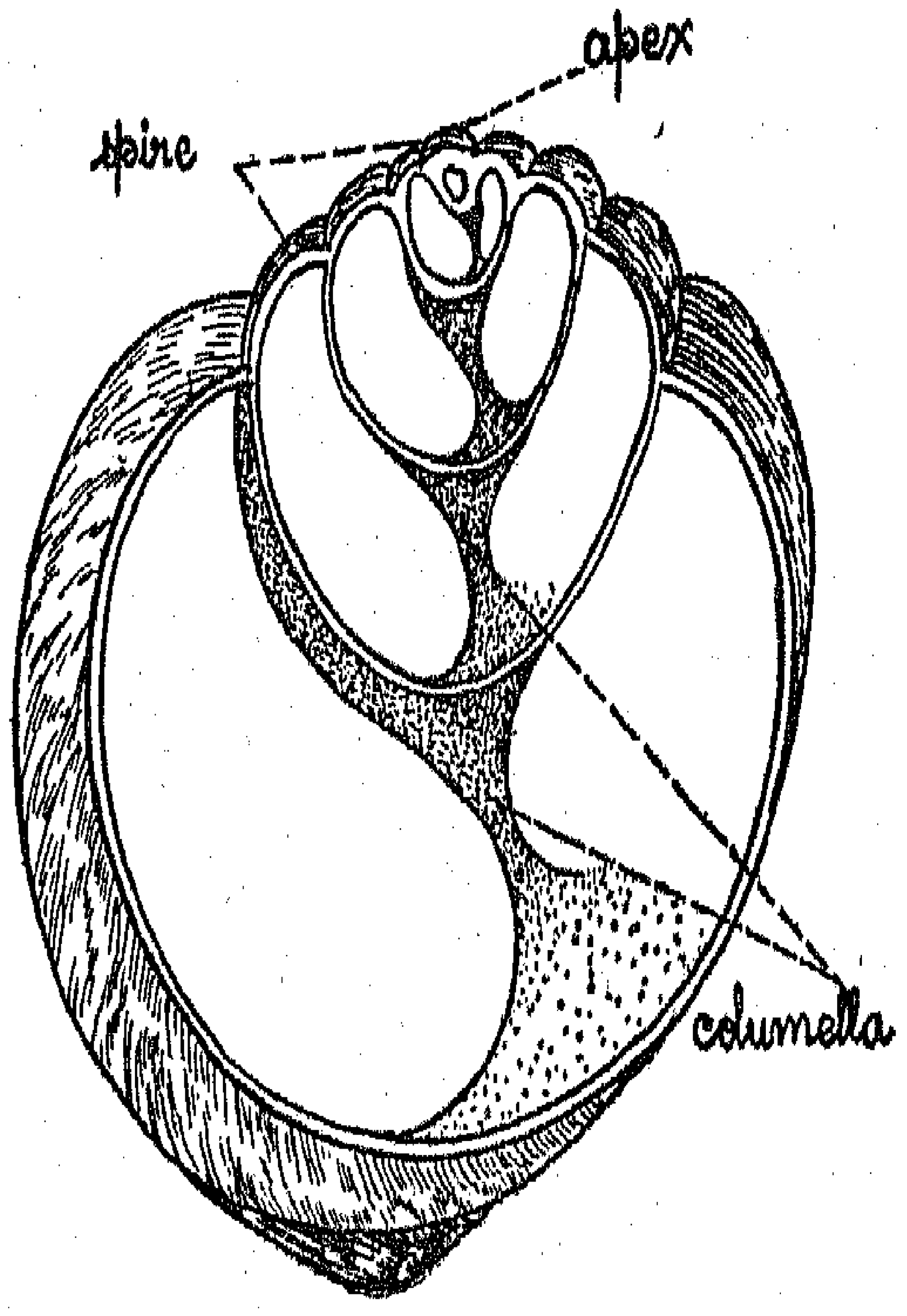

Fig. 290. Shell of Pila in section.

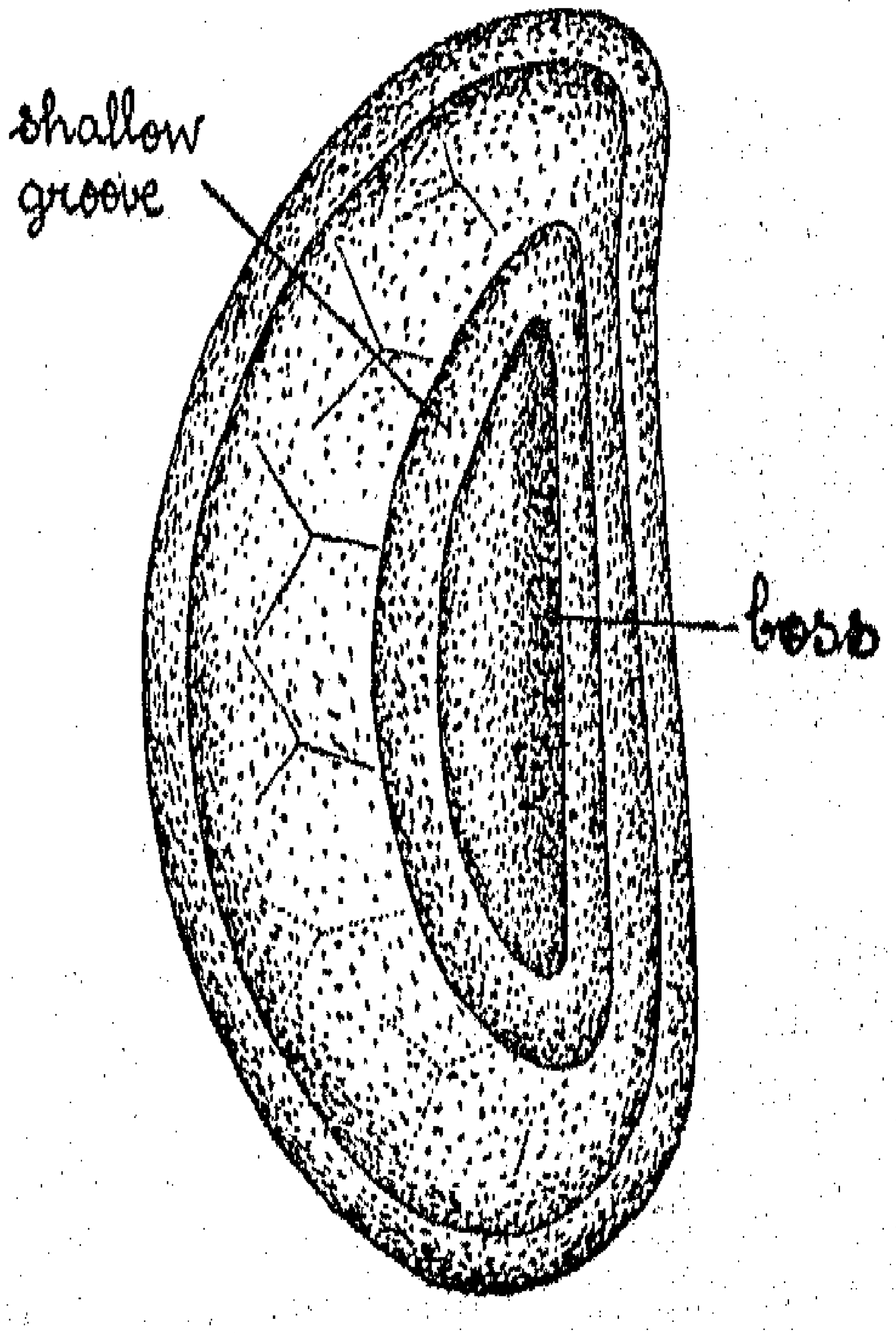

Fig. 291. Inner view of operculum.

layer which is formed mostly of $CaCO_3$. The fibrils and calcareous deposits of the two calcareous layers run at right angles to each other.

From within the shell the animal can protrude out through the opening of the shell but the visceral mass always remains within the shell. On removal of the shell the body is exposed which also shows the *whorls* corresponding to those of the shell.

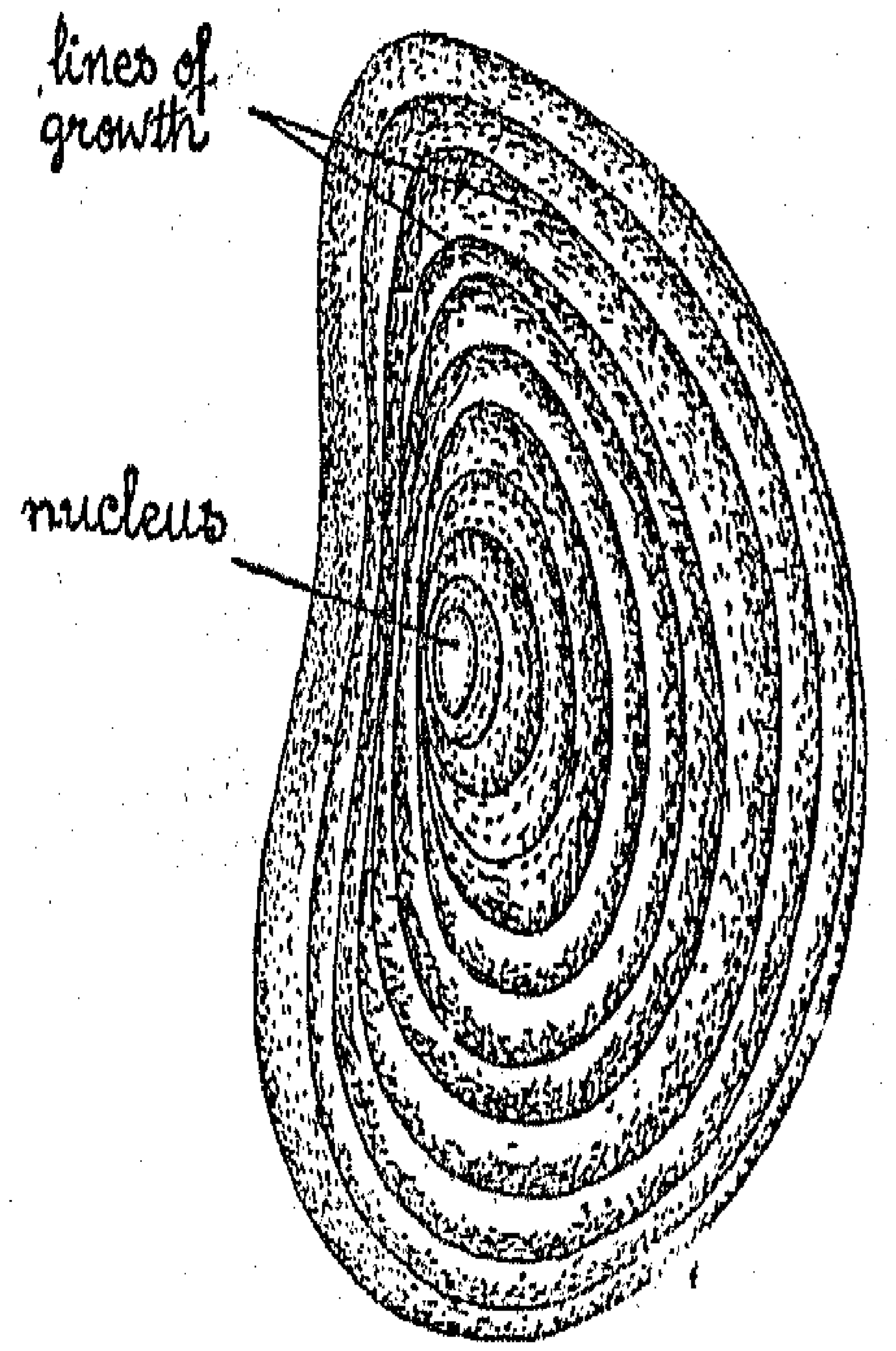

Fig. 292. Outer view of operculum.

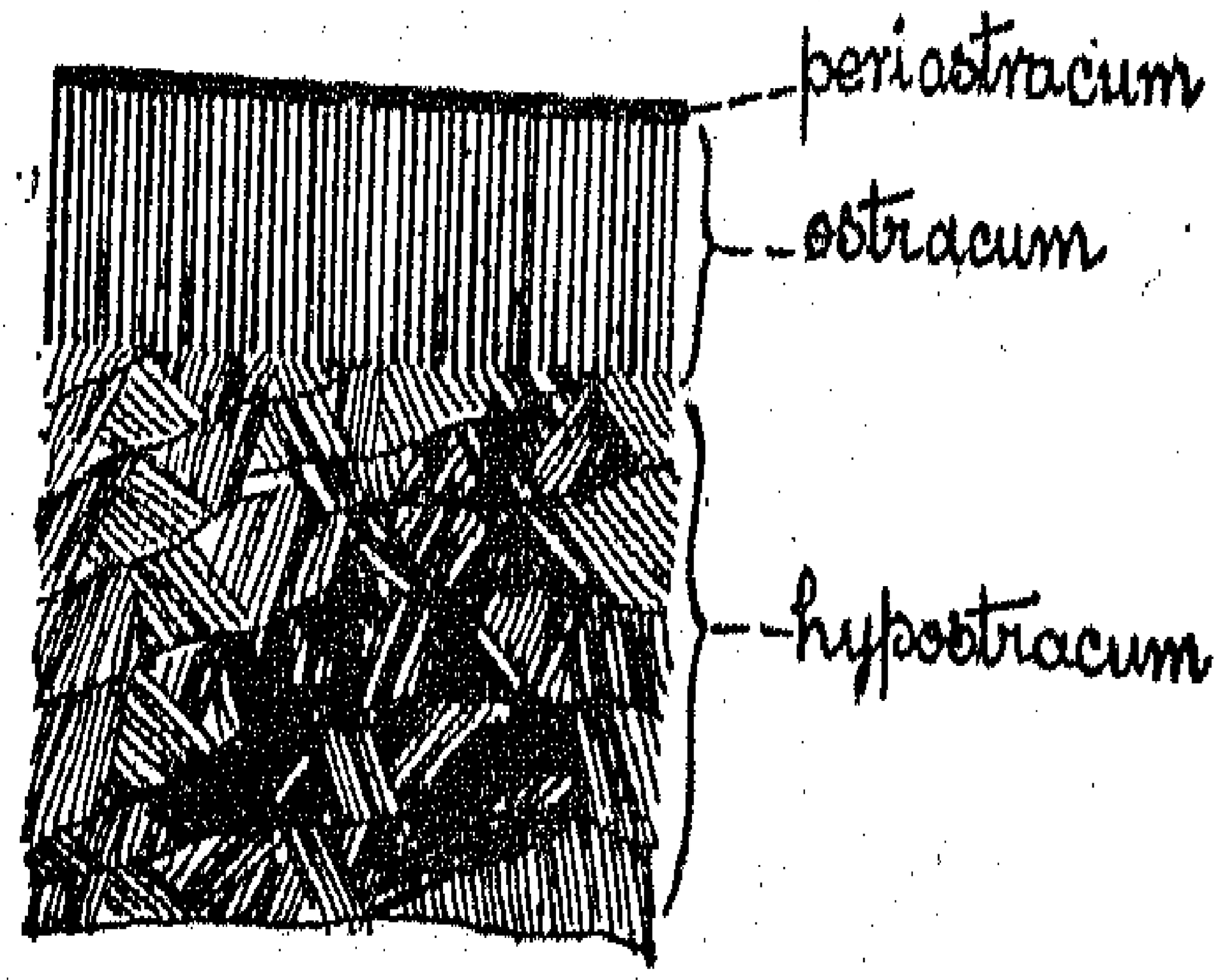

Fig. 293. Transverse section of shell.

The body consists of three parts: *head*, *foot* and visceral mass. The **head** is the anterior most part of the body and forms in front a contractile snout produced laterally into a pair of *tentacles* or the *labial palps*. The *mouth opening* lies in the median line below and between the base of these tentacles. The second pair of tentacles lies behind the first pair. At the base of each of these tentacles is found a stalk or ommatophore which bears an eye at its tip. The **foot** is a large, triangular and highly muscular organ formed by the ventral part of the body.

The **visceral mass** contains the main organs of the body. The skin of the visceral mass forms a covering flap of the body known as the *mantle*. Anteriorly the mantle forms a protective covering of the head and its appendages when they are retracted. On the sides of the head and over the foot the mantle is produced into two fleshy contractile processes: the *nuchal lobes* or the *pseudepipodia*; *these* two lobes form the *siphons* during respiration.

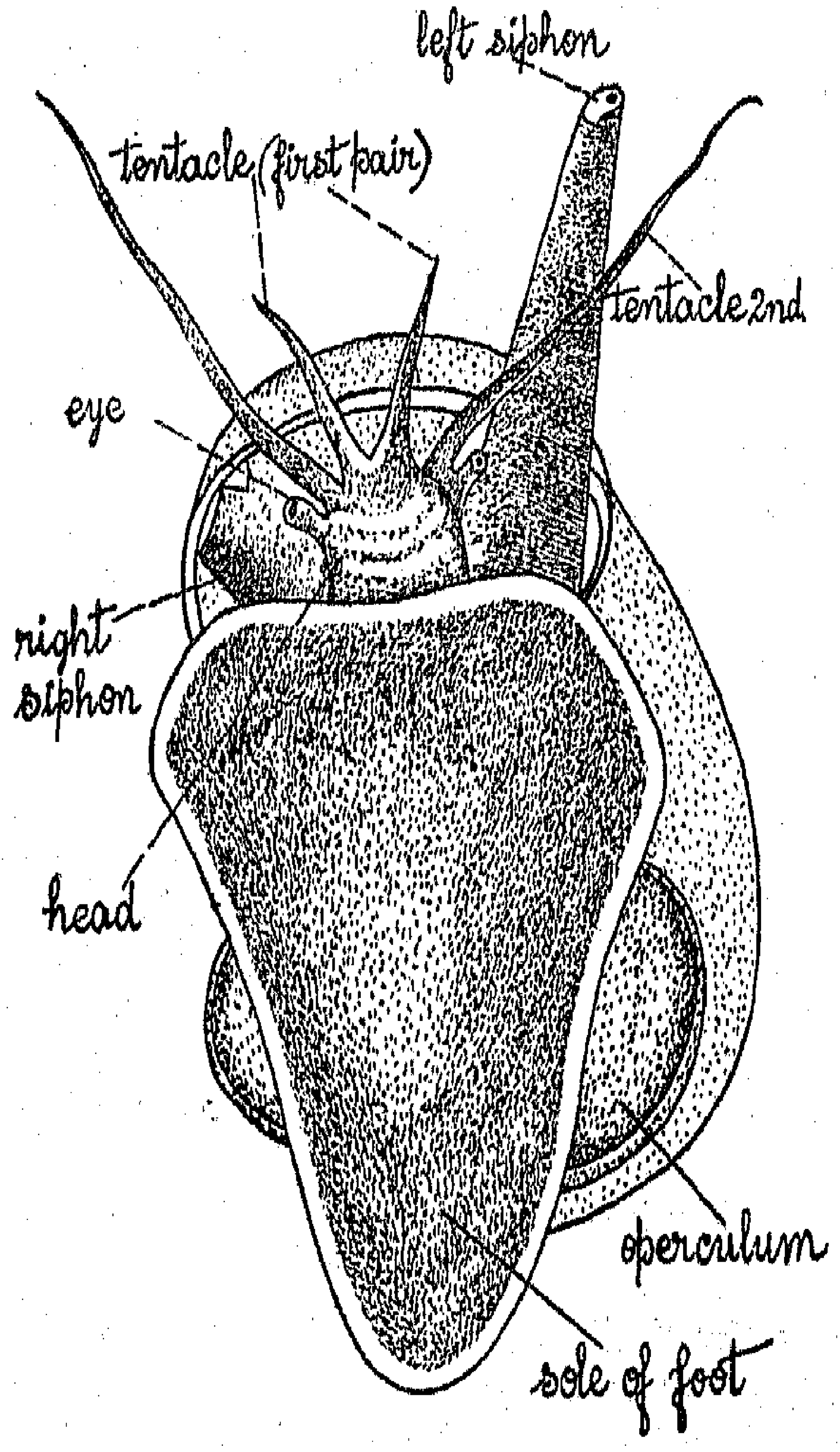

Fig. 294. Ventral view of Pila showing the broad vascular foot (Prashad).

If the mantle (which covers the body) is cut on the right side and turned to one side, a number of organs become exposed which lie in the mantle cavity. (The mantle lies on the dorsal and lateral sides of the body proper; the space between the mantle and the body is known as the *mantle cavity*. *All the organs present inside the mantle cavity are collectively spoken of as the organs of pallial complex.* Ventrally the mantle cavity is bounded by the dorsal part of the body.

Organs of the pallial complex: On the floor of the mantle cavity, arising near the edge of the right nuchal lobe is a prominent ridge known as the *epitaenia*; the epitaenia runs from the anterior edge of the right nuchal lobe to the posterior end of the mantle cavity and divides the mantle cavity into a small *right branchial chamber* and a large *left pulmonary chamber*. The branchial chamber lodges the gill or *ctenidium* which hangs vertically downwards from the dorsolateral wall of the mantle cavity. The ctenidium extends from the margin of the mantle up to the pericardium in the posterior region; it is attached to the mantle on the extreme right side of the branchial chamber. A *pulmonary sac* hangs from the roof of the mantle cavity and occupies the major part of the pulmonary chamber. The pulmonary sac opens into the mantle cavity by a longitudinal slit.

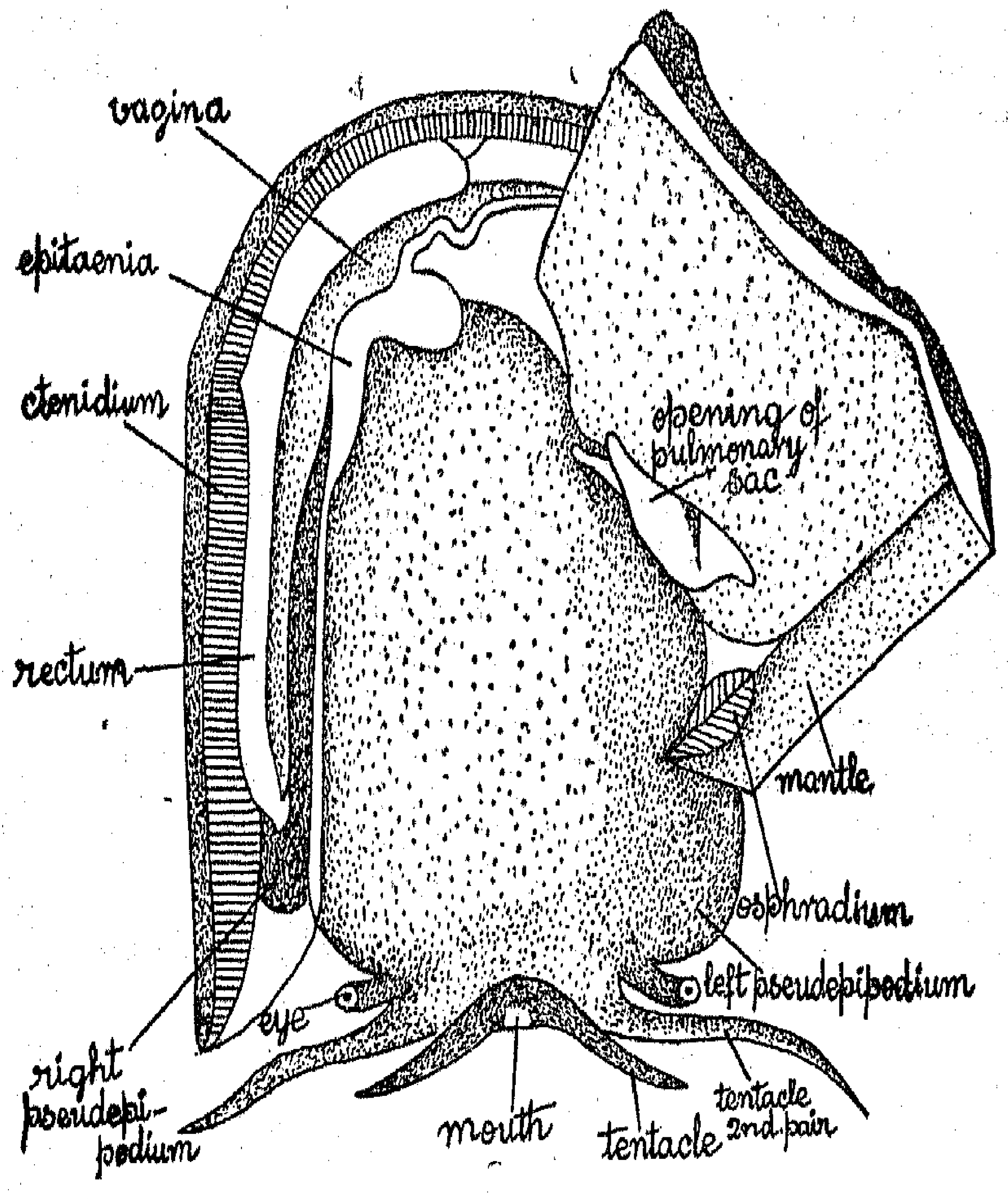

Fig. 295. Female Pila showing the structures in the mantle cavity (After Prashad).

On the left side of the ctenidium lies an elongated tube, the *rectum* with the *anus*, close to the right nuchal lobe. The male or the female duct (as the case may be) lies on the left side of the rectum. In male, a copulatory organ or *penis* arises as a separate appendage of the edge of the mantle and communicates with the terminal opening of the vas deferens only during copulation. Projecting into the branchial chamber near the hind end of the epitaenia can be seen the *anterior chamber* of the *renal organ* or *kidney*. Situated dorsolaterally on the left side of the mantle cavity near the base of the left nuchal lobe is found a bipectinate sensory structure known as *osphradium*. It has two rows of fleshy leaflets arranged along the two sides of a median axis. The *osphradium* is a sensory structure determining the purity of water. The genital opening as well as the anus lie at the anterior end of the branchial chamber.

The course of water-current: The water is drawn in through the left nuchal lobe; the aperture of the pulmonary sac into the mantle cavity is kept close. Left nuchal lobe forms a gutter-like *siphon* through which the water enters into the pulmonary chamber; the water current has naturally to flow and pass beneath the overhanging *osphradium*: the water then reaches the posterior end of the pulmonary chamber and then crossing the *epitaenia*, enters into the branchial chamber in which the water-current naturally passes over the gill, bathing the ctenidium in fresh water; thereafter the current rushes out to the exterior through the *right nuchal lobe* which also forms a gutter-like siphon.

Respiratory system *Pila* leads an *amphibious* life and is capable of utilising oxygen dissolved in water as well as that in air for its respiratory needs. It is stated that under normal conditions, it respires alternately by the aquatic and the pulmonary modes but anyone of these may predominate under certain conditions.

The organs of respiration in *Pila* include (i) a single *ctenidium* or *gill* (ii) a *pulmonary sac* and (iii) a pair of *nuchal lobes* or pseudepipodia.

The *ctendium* is situated in the branchial chamber of the mantle cavity; it is an elongated structure consisting of a single

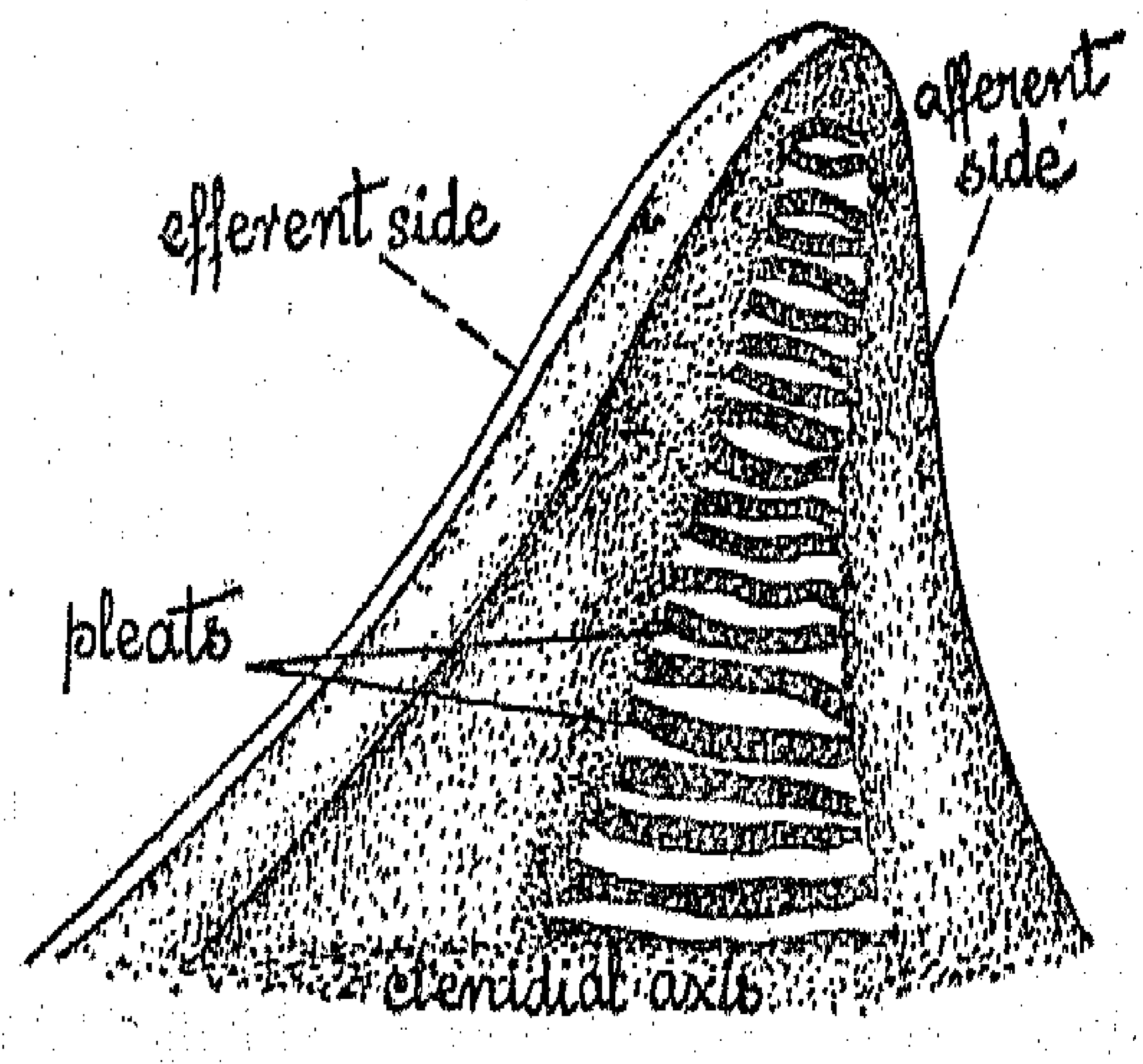

Fig. 296. A leaflet or lamella of the ctenidium of Pila.

row of thin triangular leaflets or *lamellae* borne on its axis known as the *ctenidial axis.* Such a ctenidium (i. e. with a single row of lamellae) is described as *monopectinate*; these *lamellae* are attached by their broad bases to the wall of the mantle and their apices project freely into the branchial chamber; the ctenidial axis is the line along which the leaflets are arranged on the mantle wall.

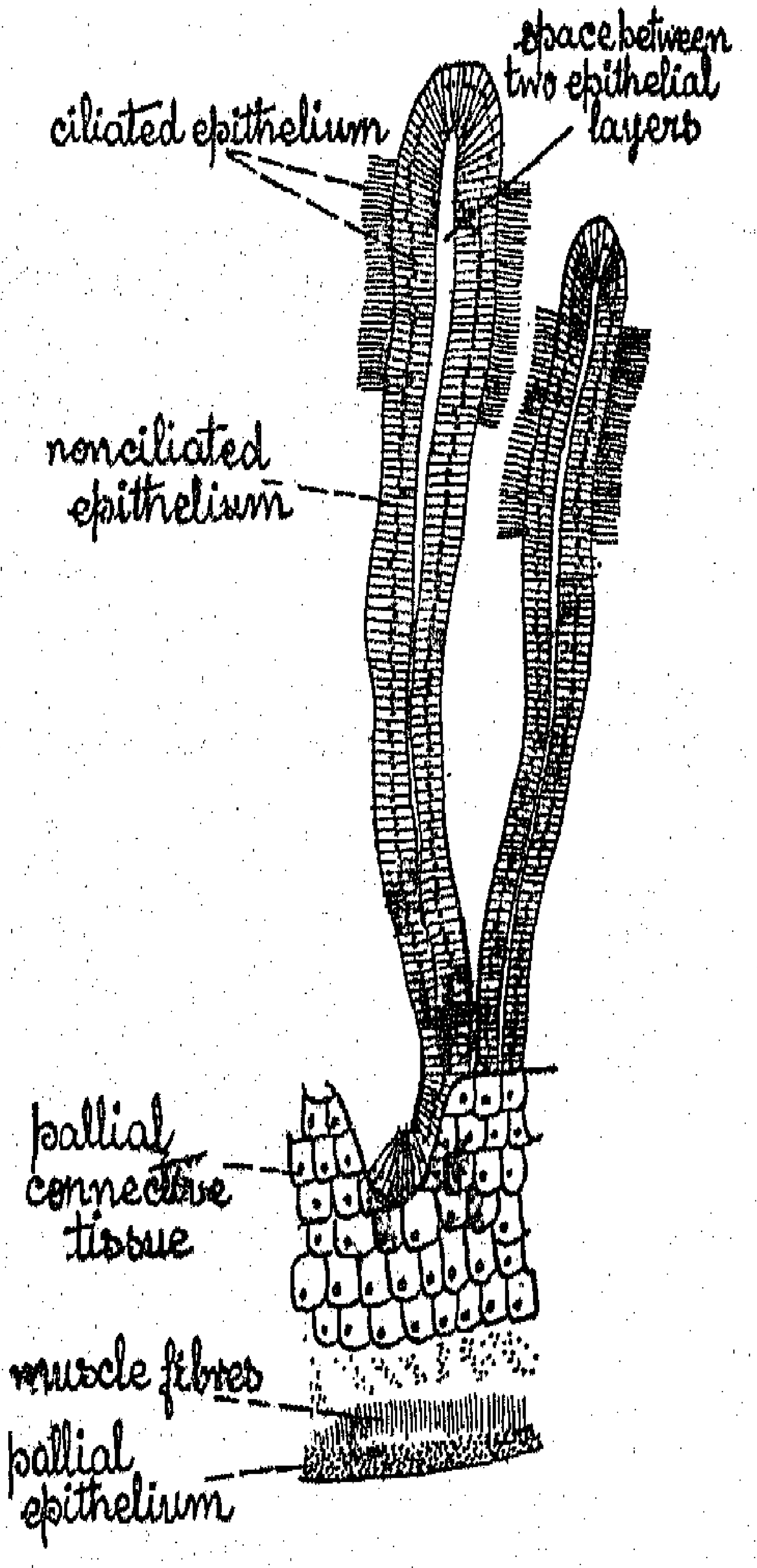

Fig. 297. Transverse section of two leaflets of ctenidium (Semidiagrammatic).

On the front and back faces of the lamellae are found richly vascularised ridges known as pleats. Each branchial lamella is formed of a double layer of epithelium; the epithelial layer consists of (i) ciliated columnar cells (ii) nonciliated columnar cells and (iii) a few gland cells; beneath the epithelium lies a thin basement membrane beneath which is a layer of connective tissue below which is the epithelium of the mantle.

During the **aquatic respiration**, the head and the foot become extended and two nuchal lobes become expanded to form small gutter-like siphons. The water is drawn through the left nuchal lobe (See fig. 294); the aperture of the pulmonary sac is kept closed. The water-current enters through the siphon

formed by the left nuchal lobe and flowing beneath the osphradium, passes on to the posterior part of the pulmonary chamber and then crosses over the *epitaenia* and enters into the branchial chamber bathing the *ctenidium* and its vascularised lamellae. Due to the constant beating of cilia of the gill lamellae, a constant water current is maintained in the branchial chamber; the alternate rising and lowering of the floor of the mantle cavity brought about by the protrusion and retraction of the snout draws in a steady current of water through the left nuchal lobe. Respiratory exchange of gases occurs on the ctenidial lamellae which are richly supplied with blood. The water current goes out to the exterior through the siphon formed by the right nuchal lobe.

The pulmonary sac is a large closed bag like structure which hangs from the roof of the pulmonary chamber and opens into it by a large opening. The pulmonary sac is derived from the mantle itself. The oval opening of the pulmonary sac into the pulmonary chamber (of the mantle cavity) is guarded by two unequal flaps. When the flaps close, the pulmonary sac becomes completely closed from the mantle cavity.

To *breath air*, the animal approaches near the surface of water and projects the *left respiratory siphon* (formed by rolling up the edges of the left nuchal lobe) above the surface of water so that free air is inhaled through it into the pulmonary chamber and thence into the pulmonary sac. The *pulmonary sac* becomes expanded and the air is drawn into it; when it contracts, the air is expelled out. Thus the inspiration and expiration are brought about by the alternate expansion and contraction of the pulmonary sac. Respiratory exchange of gases takes place in the richly vascularised walls of the pulmonary sac, and the blood becomes oxygenated. [When the pulmonary sac is filled with air, the epitaenia becomes pressed against the roof of the mantle cavity thus shutting off the branchial chamber from the pulmonary chamber. Also note that the tube formed by the left nuchal lobe establishes a direct communication between the atmosphere and the pulmonary chamber.] During the *pulmonary respiration*, lot of venous blood is received for aeration into the walls of the pulmonary sac; the oxygenated blood is collected by the pulmonary vein which delivers it to the auricle. During the aquatic respiration, large quantity of venous blood is sent for aeration to the ctenidium; the aerated blood is carried by the ctenidial vein into the auricle. When *Pila* is on land outside water, respiration occurs directly through the pulmonary sac; the left nuchal lobe is simply broadened and expanded but no respiratory siphon is formed.

Adaptations of Pila to an amphibious mode of life: The dual mode of life (i. e. terrestrial as well as aquatic) in *Pila* has been made possible by the nature which has awarded to it the capability of the dual mode of respiration i. e. the *pulmonary* as well as the *branchial*. The systems which have been specialised and modified most, in adapting it to the amphibious mode of life are (i) the *respiratory system* and (ii) the *blood vascular system.*

For the *aerial respiration,* the Nature has awarded to *Pila* a special air breathing organ, the pulmonary sac which performs function like that of a lung. *Pila* can undertake prolonged journeys on land subsisting on the aerial respiration, and successfully transfer itself to different stretches of water better suited to its life. For the *aquatic respiration,* special provision exists in *Pila* for sending blood to the ctenidium; a major supply of venous blood to *ctenidium* when the aquatic respiration predominates and a major blood supply for aeration to the pulmonary sac during the aerial respiration. Such a modification of the blood system[1] marks a definite adaptation of *Pila* to the *amphibious mode* of life.

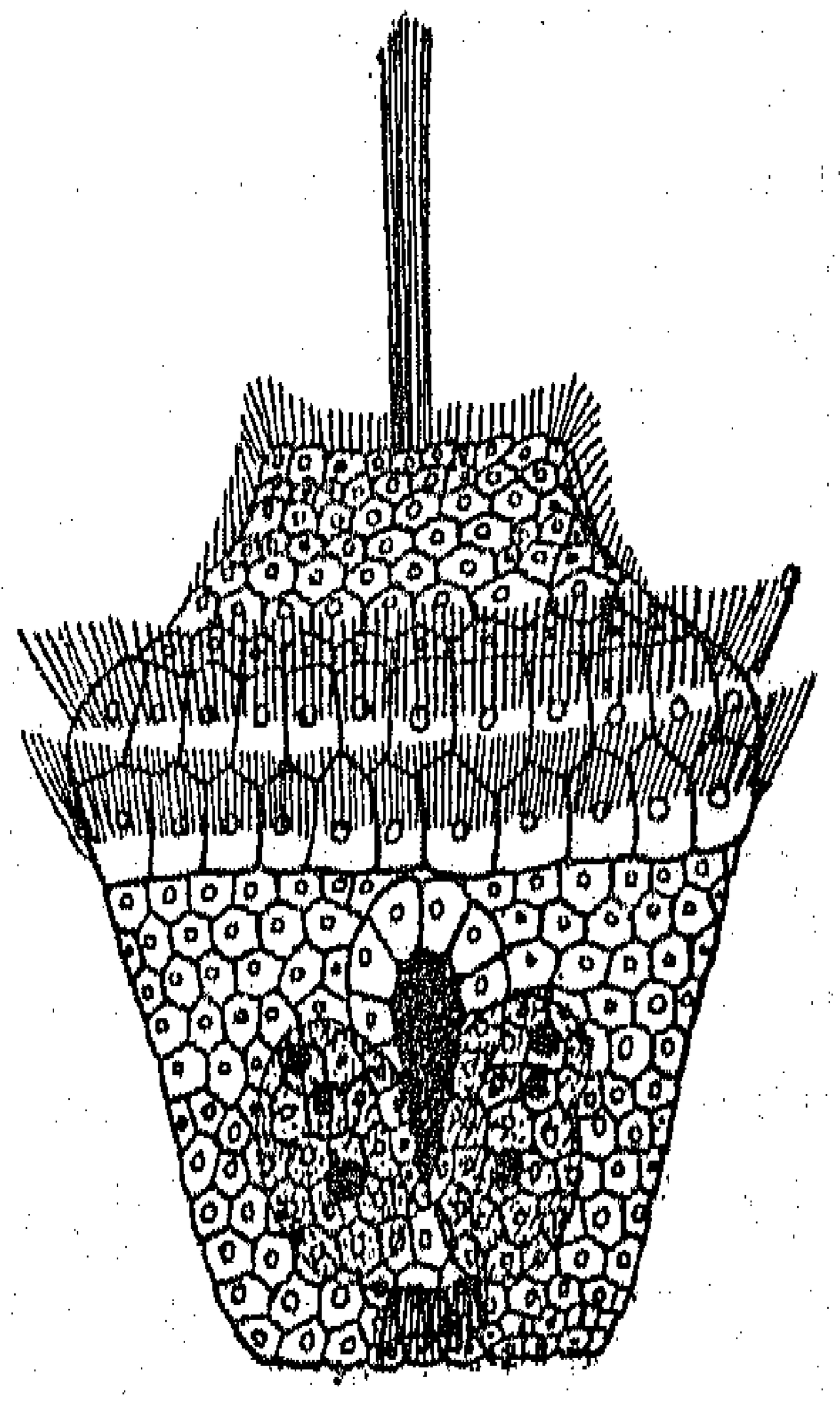

Fig. 298. A trochophore of Patella (A later stage) (From Korschelt and Heider, after Patten).

Veliger larva—In the development of gastropoda two larval stages are found, the *trochophore* and the *veliger.* The *veliger larva* has a bilobed flap-like preoral circlet bordered with strong cilia; this bilobed flap known as *velum* serves as an efficient locomotor organ and also assists in feeding; its cilia create a current of water which carries with it food particles into the mouth. The larva as shown in the diagram has besides a well developed velum, eye, cerebral ganglion, statocyst, foot and the shell which grows and starts to assume a spiral. It is this larva which will metamorphose into the adult. It may be noted that the velum of the veliger larva is developed from the prototroch of the trochophore. In the veliger stage the foot increases in size. (See fig. 300).

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[1] [For details of the blood-system in *Pila* the reader is referred to pages 1064 to 1068 of *A Text Book of Invertebrate Zoology* (1963 Edition) by **Murli Manohar Saxena.**]

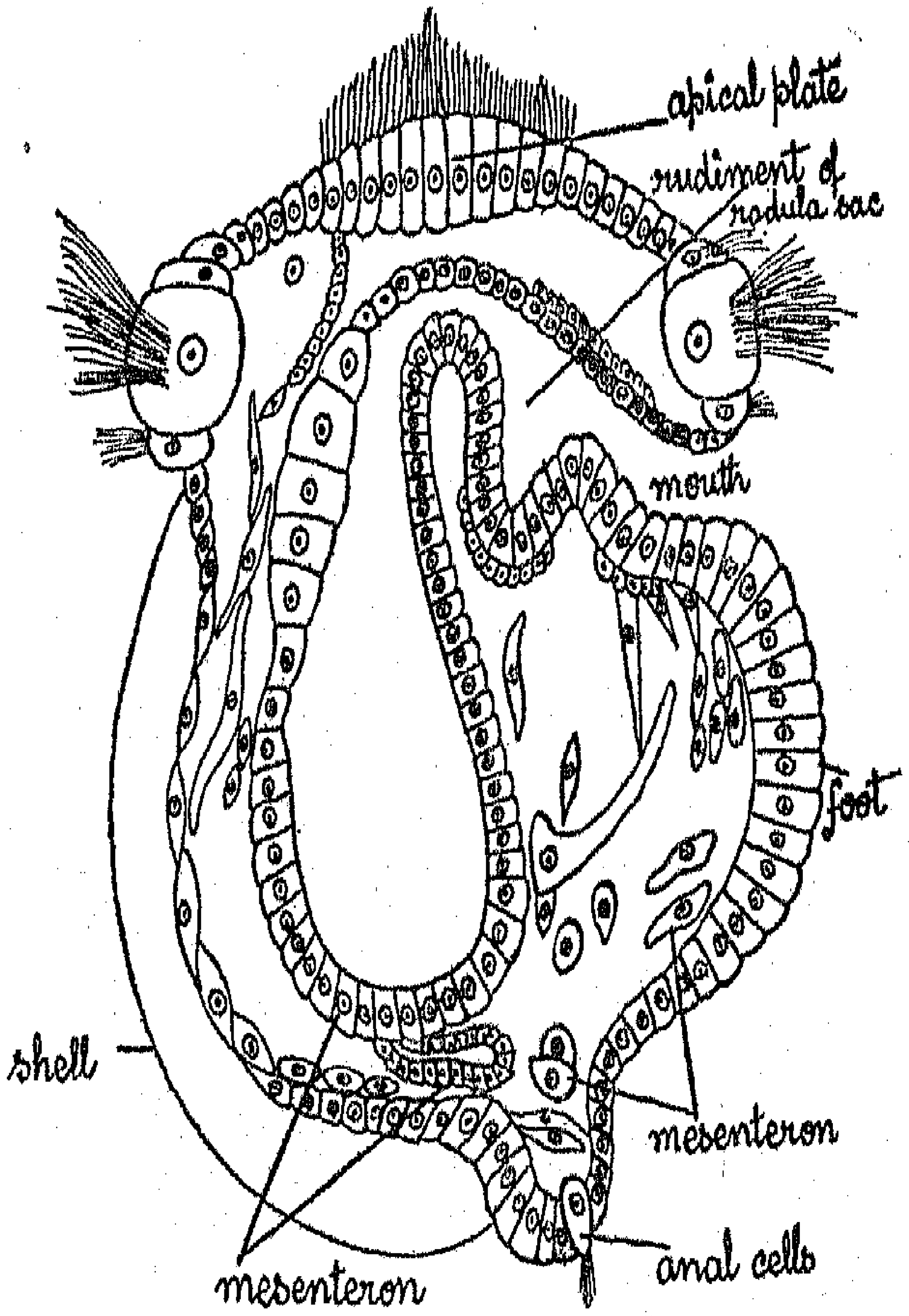

Fig. 299. Trochophoro of Patella in longitudinal section (From Korschelt and Heider, after Patten).

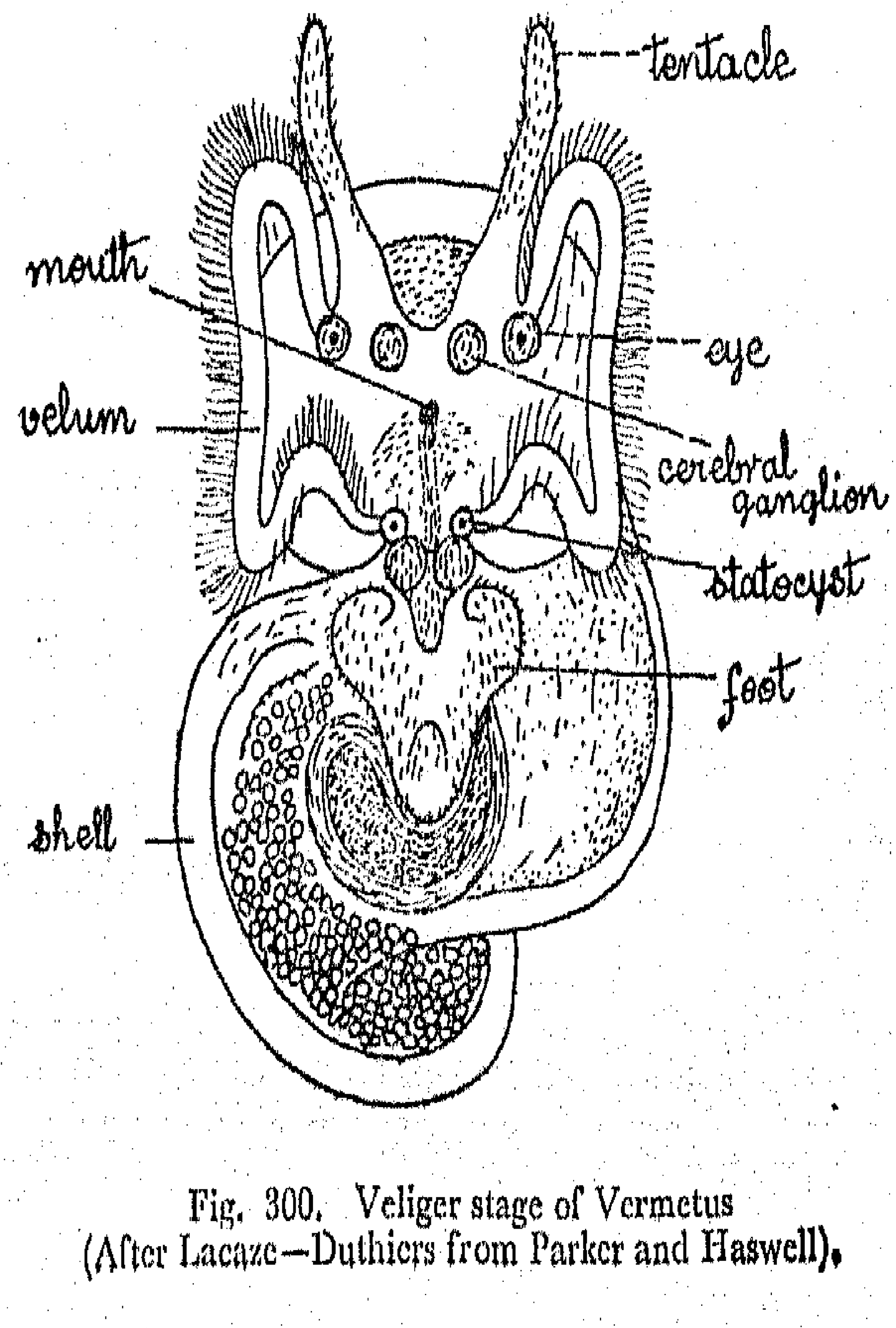

Fig. 300. Veliger stage of Vermetus (After Lacaze—Duthiers from Parker and Haswell).

49

Fresh Water Mussel--Respiratory System and Glochidium Larva

The fresh water mussel commonly found here is *Lamellidens*; *Unio* is cosmopolitan; *Anodonta cygnea* (Swan-mussel) is found in England.]

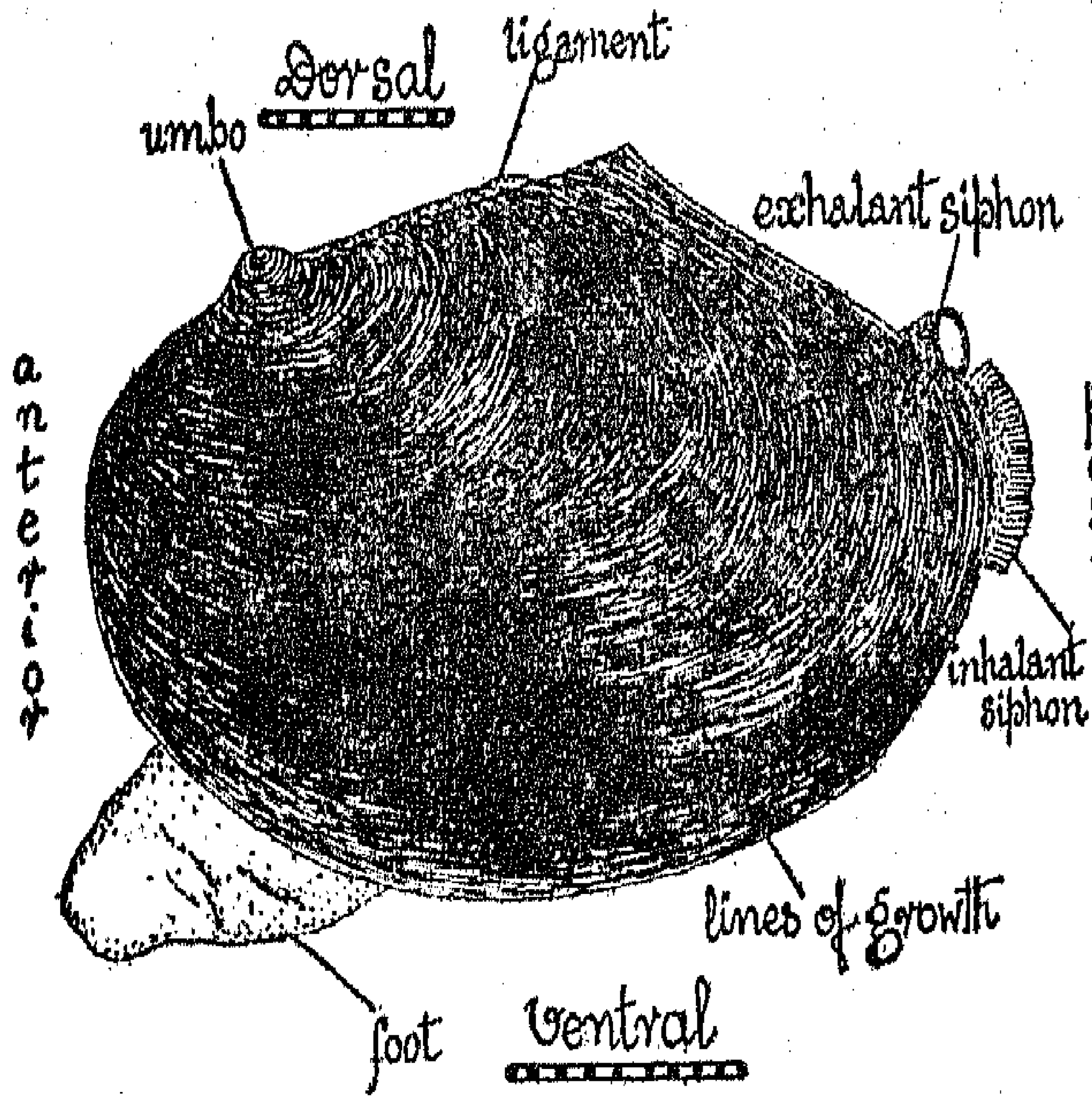

Fig. 301. Freshwater mussel viewed from the left side.

[Beneath each shell-valve lies a *mantle-lobe*; the two valves of the shell as well as the corresponding underlying lobes are right and left in position, thus marking the sides of the animal. The body proper occupies the most dorsal position and ventrally forms the foot. On each side between each of the two mantle lobes and the foot are found *two striated plate-like gills*. The space between the mantle lobes of the two sides is known as the *mantle-cavity*; the *gills*, visceral mass and foot lie inside it].

Respiratory exchange occurs through the *ctenidia* or *gills* but mainly through the medium of the *mantle*. The epithelium covering the gills and the inner surface of the mantle lobes is ciliated.

On each side there is a single *ctenidium* or gill formed of two laminae[1]. Each gill has an *outer* and an *inner lamina*. Each lamina

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1. [*Laminae*, thin plates of tissue.]

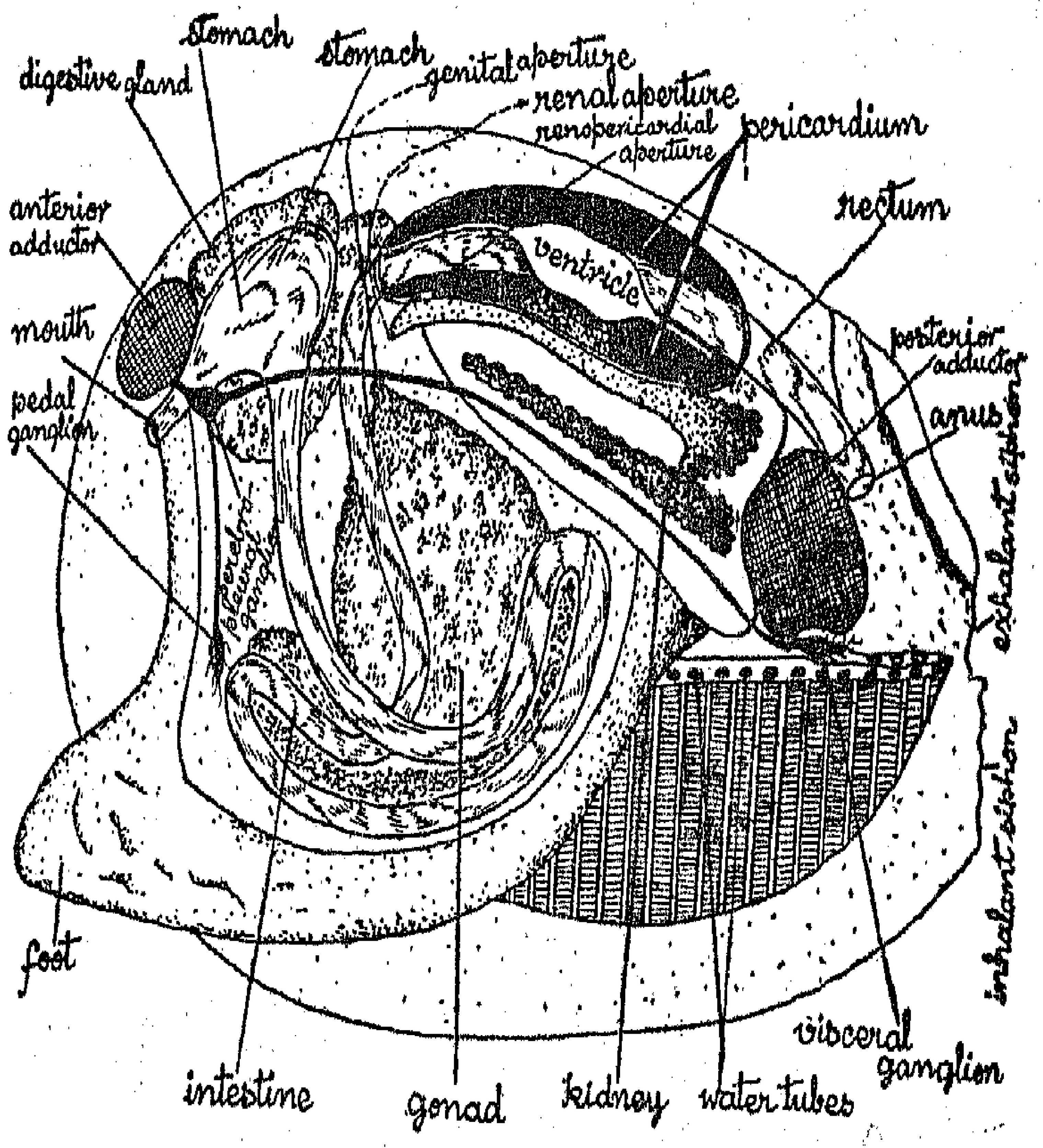

Fig. 302. The animal dissected from the left side.

is double being formed of an *inner* and an *outer lamella*, the two lamellae being united with one another along their anterior, posterior and ventral edges and free along their dorsal edge.

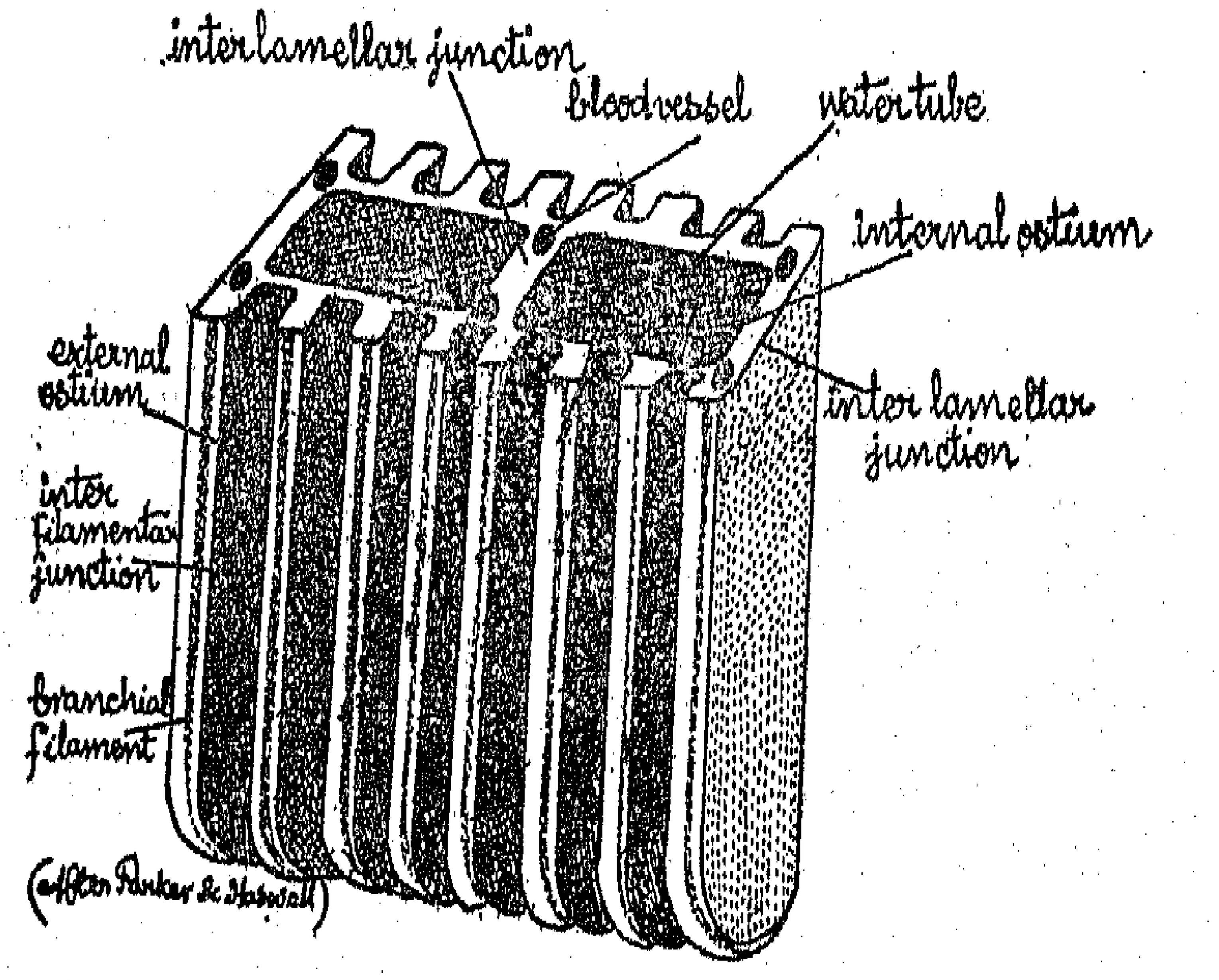

Fig. 303. Structure of gill shown diagrammatically (After Parker Haswell).

The *lamina* is thus, like a long narrow bag which is open above. The cavity of this bag is subdivided into compartments or water-tubes by the vertical bars of tissue extending between the two lamellae; the water-tubes are closed on their ventral side and open along the dorsal edge of the ctenidium. On its surface, each lamina exhibits a double *striation* due to certain lines running parallel to the long axis of the lamina and the others running at right angles to it in a *vertical direction*, the *latter* being due to the fact that each gill lamella is formed of the close-set gill filaments; the longitudinal striation is due to the horizontally running *interfilamentar junctions* which connect the gill filaments. The filaments of the two lamellae are continuous at their ventral edges, so that the lamina consists of a series of U-shaped filaments. The inner and outer limbs of these U-shaped filaments respectively form the inner and outer lamella of each lamina. Minute apertures, the *ostia* bounded above and below by the interfilamentar junctions and occurring between the gill filaments lead from the mantle cavity through irregular paths in the water tubes. The outer epithelium of gill filaments is ciliated and due to its ciliary action a current of water is maintained.

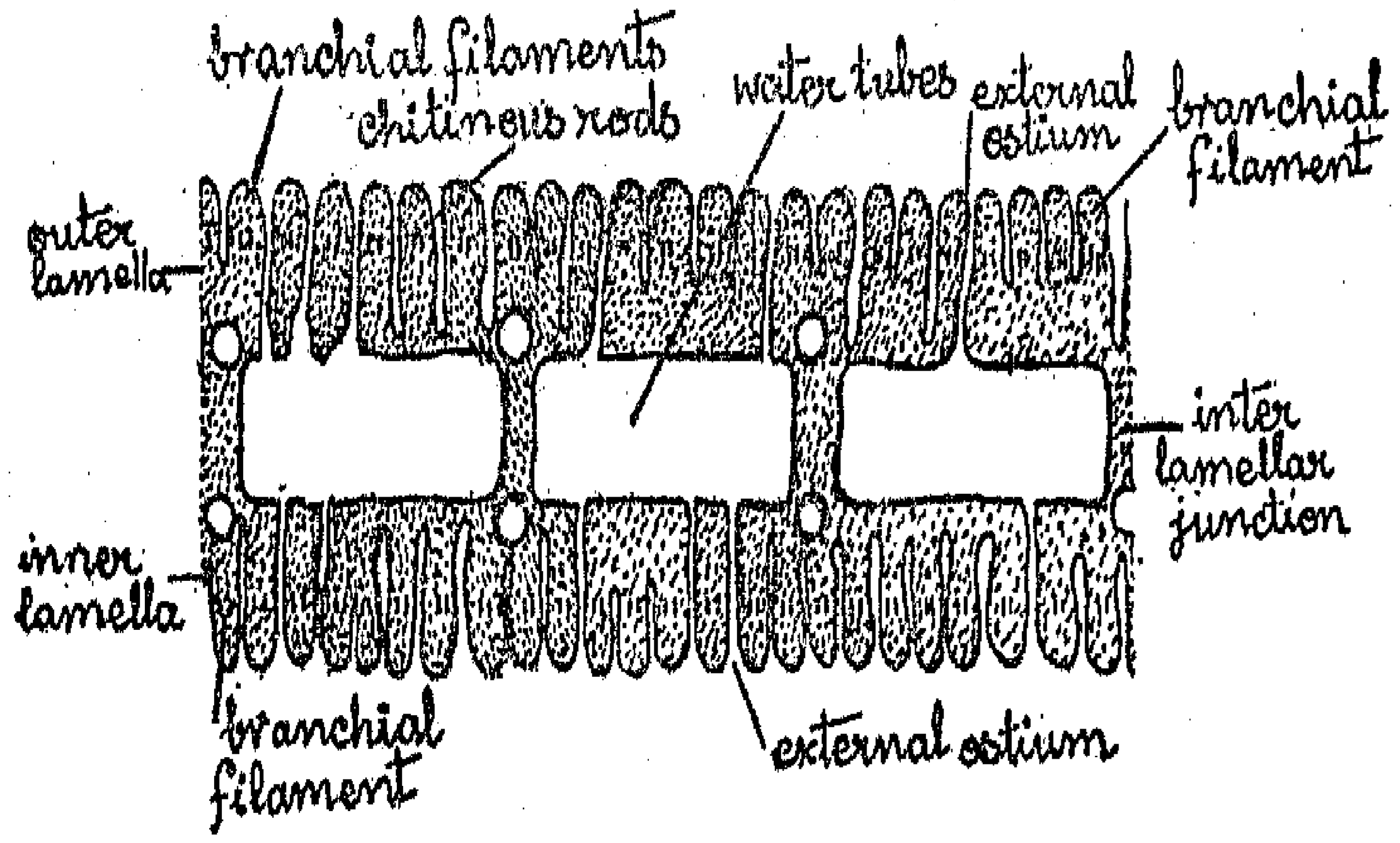

Fig. 304. Transverse section of outer gill lamina.

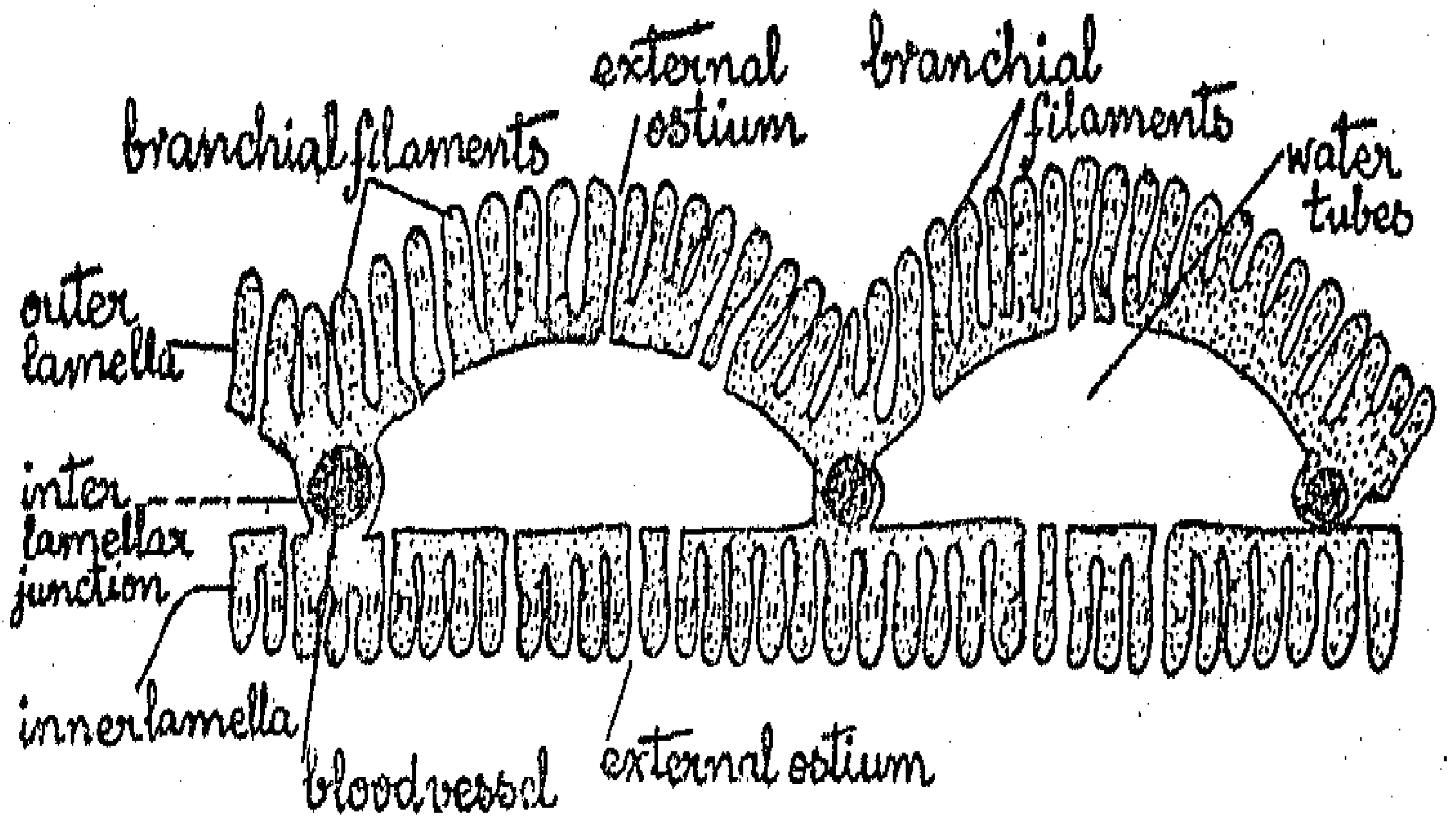

Fig. 305. Transverse section of inner gill lamina.

The outer lamella of the outer lamina is attached along its entire length to the mandle; the inner lamella of the outer and the

outer lamella of the inner lamina are attached together on the sides of the visceral mass slightly below the place where the mantle arises. The inner lamella of the inner lamina is also attached to the visceral mass anteriorly but is free in the region

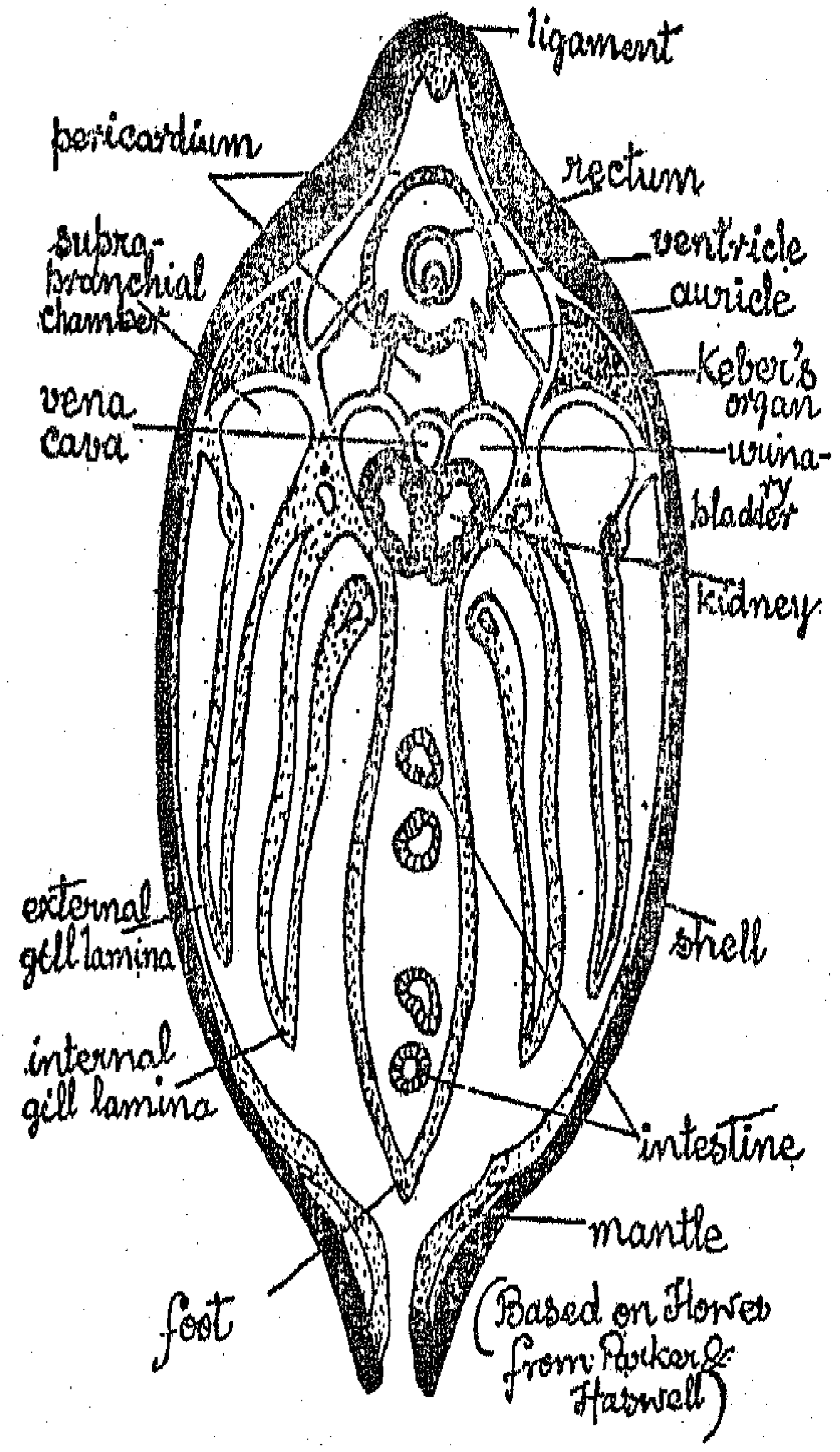

Fig. 306. Transverse section of the fresh water mussel passing through the heart to show the relative position of gills and other structures in the mantle cavity.

far behind. The *gills* are longer than the visceral mass and *project behind* it below the posterior adductor muscle up to the posterior edge of the mantle where the inner lamellae of the inner laminae of both the sides (right and left) are united together; in this region a *horizontal partition* is formed by the dorsal edges of the four laminae (taking those of both the sides). This horizontal partition divides the mantle cavity into a lower *pallial cavity* and an upper *epibranchial cavity*. The current of water enters the (ventral) inhalant siphon→(lower) *pallial cavity*→ ostia→water tubes→dorsal apertures of water tubes→(upper) epibranchial cavity (or the supra branchial chamber)→cloaca→ exhalant siphon (dorsal)→exterior.

The *current* of *water* containing oxygen for the aeration of blood (and also Diatoms, Infusoria and other micro-organisms) *proceeds* towards and into the mouth by ciliary action. The waste products discharged from the anus and excretory products pass out through the exhalant siphon.

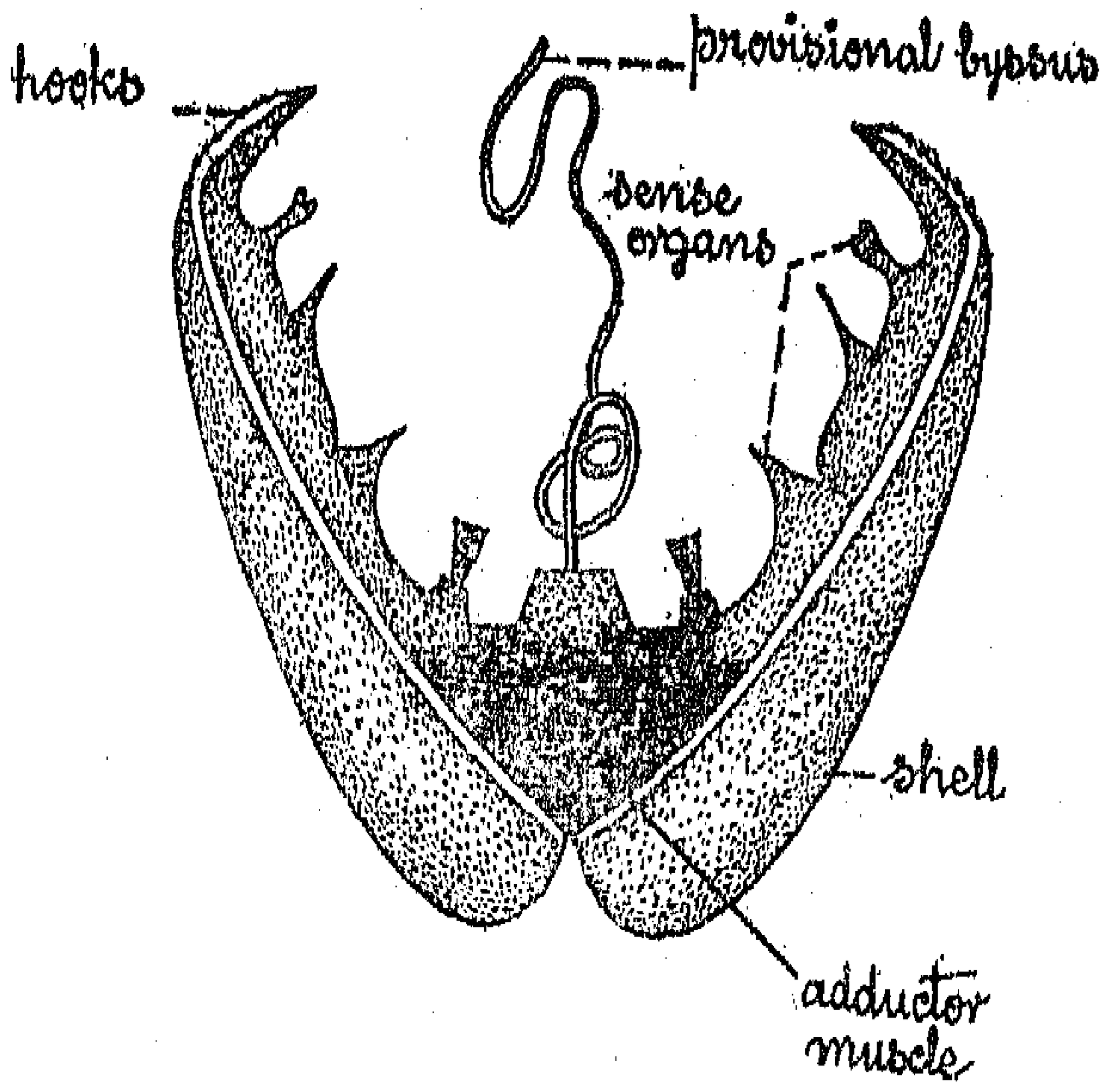

Fig. 307. Free Glochidum larva (Korschelt and Heider).

Glochidium larva is the larva of the fresh water mussel. The outer gill laminae serve as brood pouches; soon the eggs develop into the *glochidium larva*. The body of the larva lies inside the shell; soon the body forms right and left mantle lobes and the body proper occupies a more dorsal position. A long thread the *provisional byssus* is secreted from a glandular pouch which is formed on the ventral surface. Brush like sense organs develop on the mantle lobes. Extending between the two valves is formed an adductor muscle developed from the mesoderm. Now the larva is known as the *Glochidium*. It is nourished by a secretion from the walls of the brood pouch (cavities of the outer gill laminae). These larvae are then ejected out to the exterior from the exhalant siphon. They cannot swim and sink to the bottom, or, are carried by the water current. Later on, they become attached to the gills or body of a fresh water fish; the larvae get buried in its integument; the attachment is secured by means of the hooked valves of the *glochidium*.

[The larva remains in this position for about ten weeks as an ectoparasite. It undergoes a metamorphosis, gets detached, gives up the ectoparasitic life and gradually becomes a full fledged adult].

50

Classification of the Phylum Mollusca

1. **Give the diagnostic characters of the phylum Mollusca. On what characters this phylum is divided into various classes.** (L. U. B. Sc. Pass, 1959)

2. **Classify Mollusca giving diagnostic characters and examples of each group.** (L. U. B. Sc. Prel., 1955)

The **molluscs**[1] are soft-bodied *coelomate* animals *lacking segmentation* and possessing a *dorsal visceral hump*, a *ventral muscular foot* and *soft skin*. The skin covering the visceral hump, the *mantle* secretes a **calcareous shell**; the skin covering the visceral hump is produced into flaps or *mantle lobes* which partially enclose a mantle cavity into which open a pair of *renal organs* and the *anus*. In the mantle cavity are found *ctenidia* or gills. There is an alimentary canal; usually a *buccal mass*, a *radula* and *salivary glands*; a *stomach* is present in which opens a 'hepatopancreas' (digestive gland). The respiratory pigment in blood is *haemocyanin*; the heart has a ventricle and two auricles; there are arteries and veins which form sinuses (haemocoele). In the nervous system are found a *circumoesophageal ring*, *cerebral* and *pleural ganglia*, pedal ganglia and visceral loops. The coelom is represented by the cavity of the gonads, kidneys and the pericardium. The larva is often a *trochophore*.

The major **molluscan classes** are best differentiated on the basis of the character of their **shell**; the characters of foot, mantle, gills and nervous system are also considered as criteria for the classification. The phylum Mollusca is divisible into *five classes*.

Class I **Amphineura** are bilaterally symmetrical and elongated with no tentacles or eyes on head, the head region is not distinctly separated off and is tucked under the mantle. The mantle covers the entire dorsal surface and has calcareous *spicules* in its superficial cuticle. The *spicules* may form a shell. The *mouth* and the *anus* are found at opposite ends of the body. The foot is flattened and used for creeping and for adhering on to the surface. The foot may be reduced in some. The nervous system lacks definite ganglia. There is a circumoesophageal commissure and two pairs of longitudinal cords each of which is united in the posterior region by a commissure. A *radula* is present in the buccal cavity. Example: *Chiton*.

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[1] [**Mollusca**, L. *molluscus*, softish; *mollis*, soft].

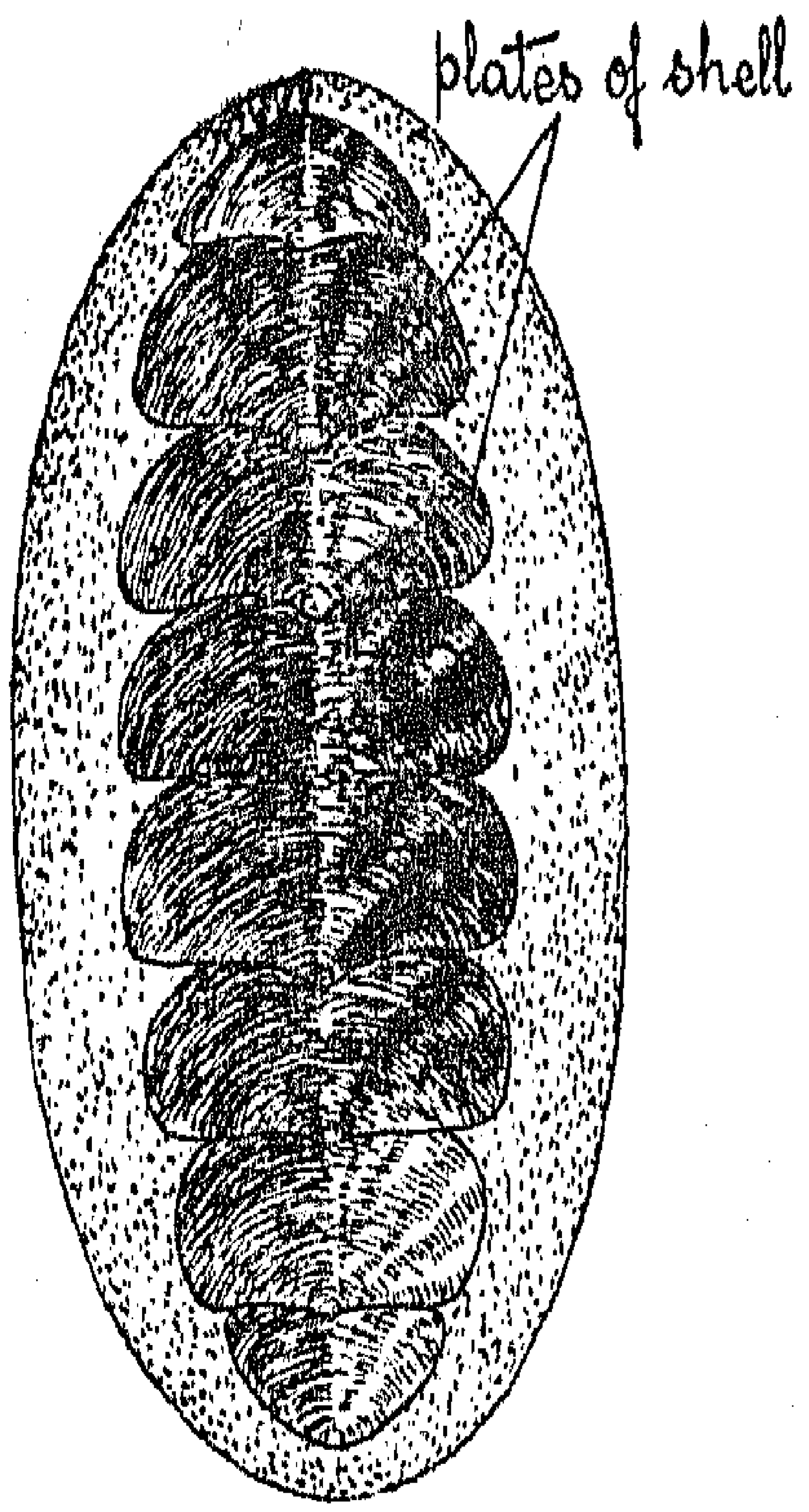


Fig. 308. Chiton (Dorsal view).

Chiton has a dorsoventrally compressed body with a broad *flat foot* (used for creeping) on the ventral side and a *calcareous shell* (made up of at least *eigth pieces* or *valves* arranged in a longitudinal row one behind the other and partly covered over by the mantle). The mantle lobes are very slight *lateral flaps* beneath which are groove-like spaces in which are found 14 to 80 small *ctenidia*; these small spaces covered over by the mantle lobes and accommodating the ctenidia represent the *mantle-cavities.* The buccal cavity has a muscular *odontrophore* bearing a rasping *radula.* There is a long coiled intestine. An extensive coelom is found which is represented by three separate compartments: the general body cavity, the pericardial cavity and the cavity of gonads. At the sides of the mouth are found a pair of *labial* palps. The head is not distinctly demarcated and bears no eyes and tentacles. The animals are unisexual and the larva is a *trochophore* which lacks primitive nephrida differing in this character from the annelidan trochophore. *Chiton* is marine and is found abundantly on the shore between tidal limits. It lives upon minute algae and diatoms. It moves sluggishly if at all and remains adhered on the surface of rock by its foot; when detached it becomes ball-like and on removal of the disturbance it gradually resumes its normal form.

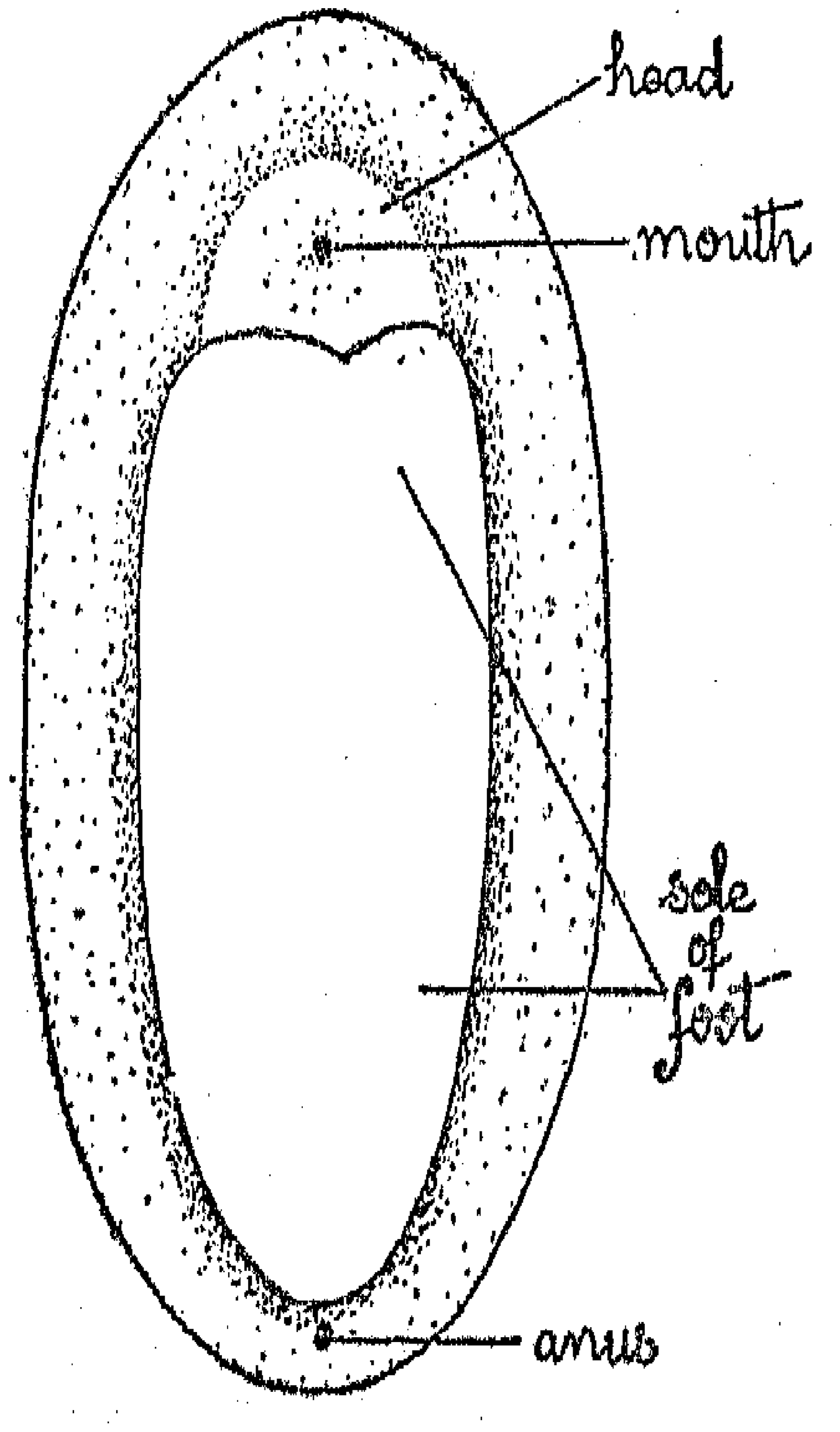
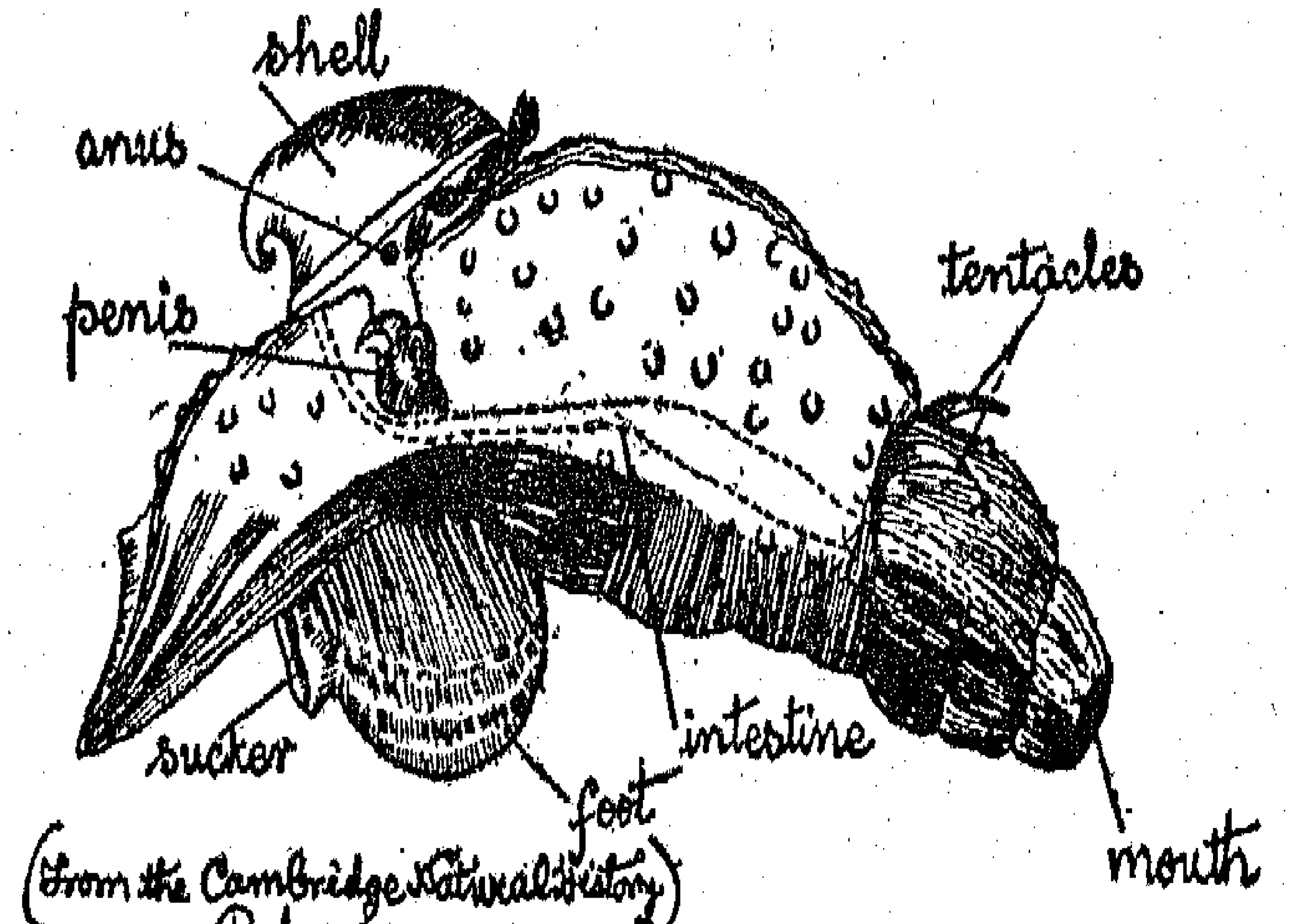


Fig. 309. Chiton (Ventral view).

Class II **Gastropoda** have a *distinct head* bearing eyes and tentacles, a flattened foot and a visceral hump. *The shell consists of a single spirally coiled valve* and the visceral mass also exhibits the phenomenon of torsion and is spirally coiled. In the nervous system there are cerebral, pleural, visceral and pedal ganglia and a visceral loop. The buccal cavity has an odontophore with a radula bearing teeth. The larval stages are the *trochophore* and the *veliger*. The class is divided into three orders:

Order 1 **Prosobranchiata** exhibit torsion, shell with an operculum+ctenidia situated in front of the heart, the mantle cavity opens anteriorly; the visceral loop is twisted in the form of a figure of '8'. Sexes are separate. Examples are *Haliotis*, *Patella*, **Carinaria**, *Buccinum Pila* etc.

Carinaria belongs to the suborder **Monotocardia** of this order; [**Monotocardia**, single auricle and ctenidium, the ctenidium has only one row of gill leaf-lets, the gonads possess separate ducts opening in the mantle cavity far forwards, the male has a well-formed *penis*. *Carinaria* is a pelagic form and swims with the help of its foot, the anterior portion of which is compressed and



(From the Cambridge Natural History) Redrawn.

Fig. 310. Carinaria sp. (Male).

fin-like and the posterior part is prolonged backwards. The anterior portion of the laterally flattened foot is produced ventrally and in males it bears a sucker. The head is large while the visceral sac (containing the visceral mass) and the mantle form a small part of the body. The gills are situated on the dorsal side and are protected by the shell. The anus is located on the dorsal side near the gills.

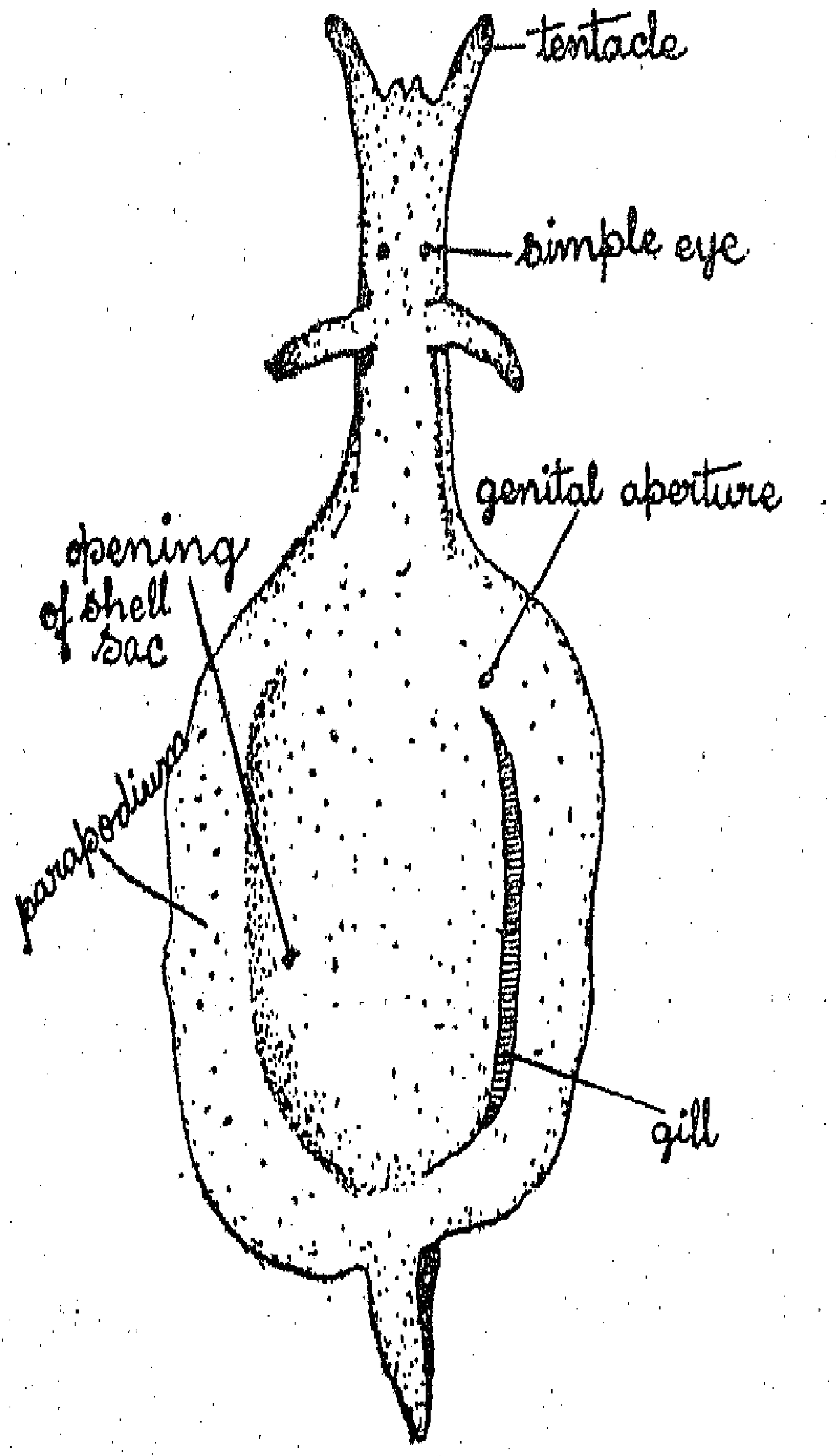


Fig. 311. Aplysia (Dorsal view).

Order 2. **Opisthobranchiata** are hermaphrodite, exhibit a reversal of torsion (*detorsion*); the mantle cavity tends to become posterior in position; the shell is small, may be absent or it may be internal; the *ctenidium* is *single* or it may be substituted by accessory respiratory organs, the *branchiae*. In some forms, the entire external surface may perform the respiratory function. Respiration is aquatic and the forms are marine. *Aplysia* and *Doris*.

Aplysia (Sea-hare): the head bears two pairs of tentacles of which the posterior pair is olfactory and bears at its base a pair of simple eyes. The foot has developed a pair of fin-like lateral lobes known as *parapodia* which help in swimming. The mantle is reflected over and covers most of the area of the *greatly reduced shell*. The ctenidium points backwards in the mantle cavity which lies towards the right. The animal is hermaphrodite.

There is a well developed symmetrical visceral loop in the nervous system. A crop with horny plates is found in the alimentary canal in which mastication occurs.

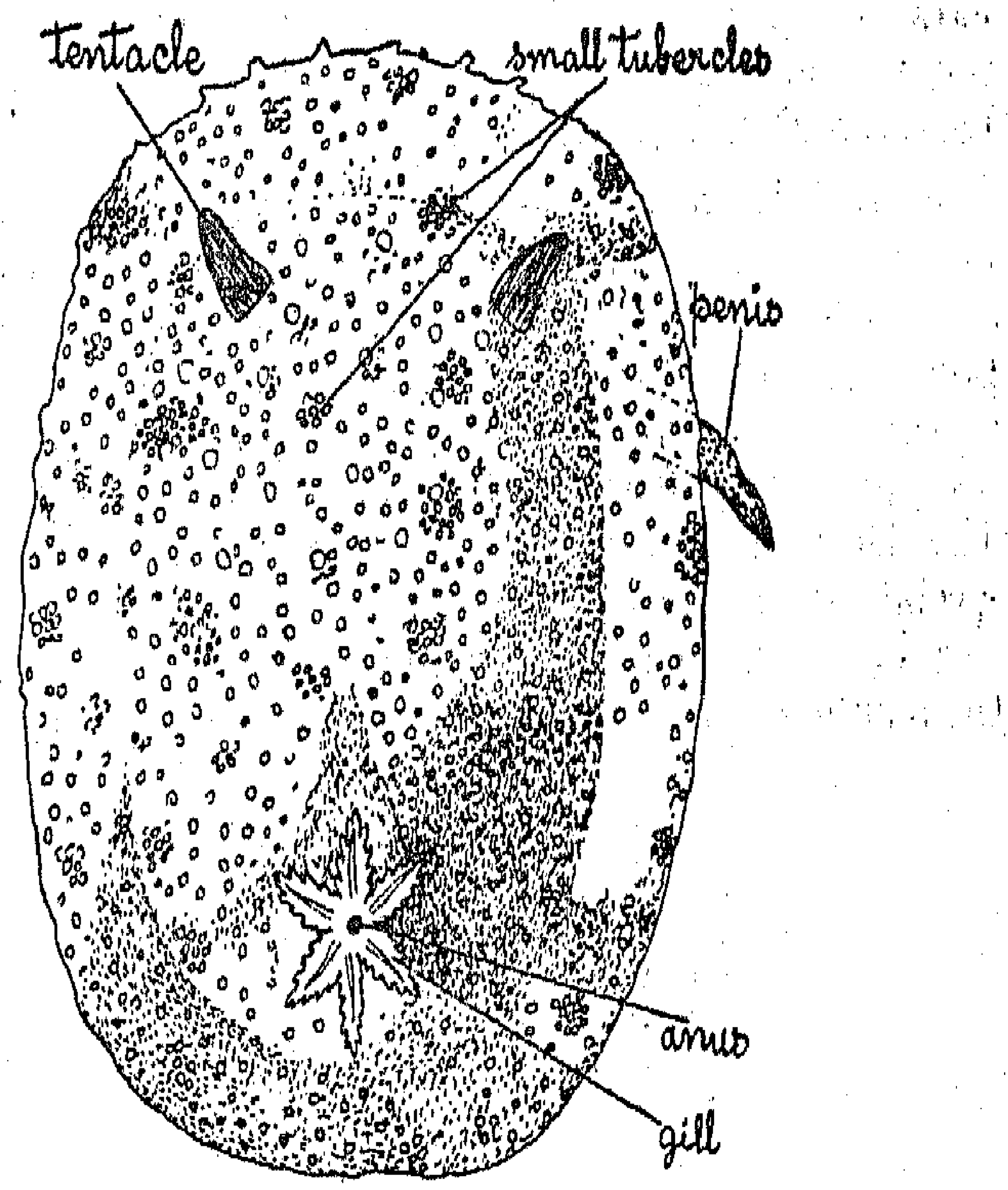


Fig. 312. Doris.

Doris (Sea-lemon) is short flattened nudibranch[1], a sluggish creature with a tough pigmented mantle reinforced with calcareous spicules. The colour of the mantle simulates that of the substratum: encrustation of sponges etc., upon which it also feeds. The anterior region bears a pair of short tentacles. Surrounding the anus (at the posterior end in the median line) is found a tuft of accessory gills or secondary branchiae. The kidney is median and the renal aperture is located a little in front of the anus. The kidney is median. The shell is reduced and there are no ctenidia or osphradia. The mantle covers the greater part of the body and externally the body appears to be symmetrical.

Order 3. **Pulmonata** include hermaphrodite gastropoda with two pairs of tentacles. Ctenidia are lacking and respiration occurs through the wall of the mantle cavity which functions as a lung. The mantle cavity has a vascularised roof and opens by a small contractile aperture, the *pneumatostome*. There is a single kidney. The nervous system has ganglia concentrated into a circumoesophageal ganglionic complex; the connectives are short as a result of which the nervous system assumes secondarily a bilateral symmetry. The development is direct. The **Pulmonata** have a remarkable terrestrial habit supported by pulmonary respiration. Examples: *Limnaea*, *Planorbis* (fresh water forms), Land snails (*Helix*), slugs (*Limax*).

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[1] The order **Opisthobranchiata** is divisible into two sub-orders: (i) **Tectibranchiata** which often have a shell and mostly a mantle cavity and ctenidium, e. g. *Aplysia* and (ii) **Nudibranchiata** which have neither a shell, nor a mantle cavity nor a ctenidium. *Doris* is a nudibranch.

Class III. **Scaphopoda** are bilaterally symmetrical and possess a *tubular shell* open at both ends. The foot is reduced and helps in burrowing. The head has many prehensile processes. The circulatory system is rudimentary and there are *no ctenidia*. A *radula* is present in the buccal cavity. In the nervous system there are separate cerebrial and pleural gangila. The larva is a *trochosphere*. The forms are marine and are specialised in burrowing. At the time of burrowing, the apex remains above the sand surface and through it enter the water into the mantle cavity. Water also leaves by the opening at the apex.

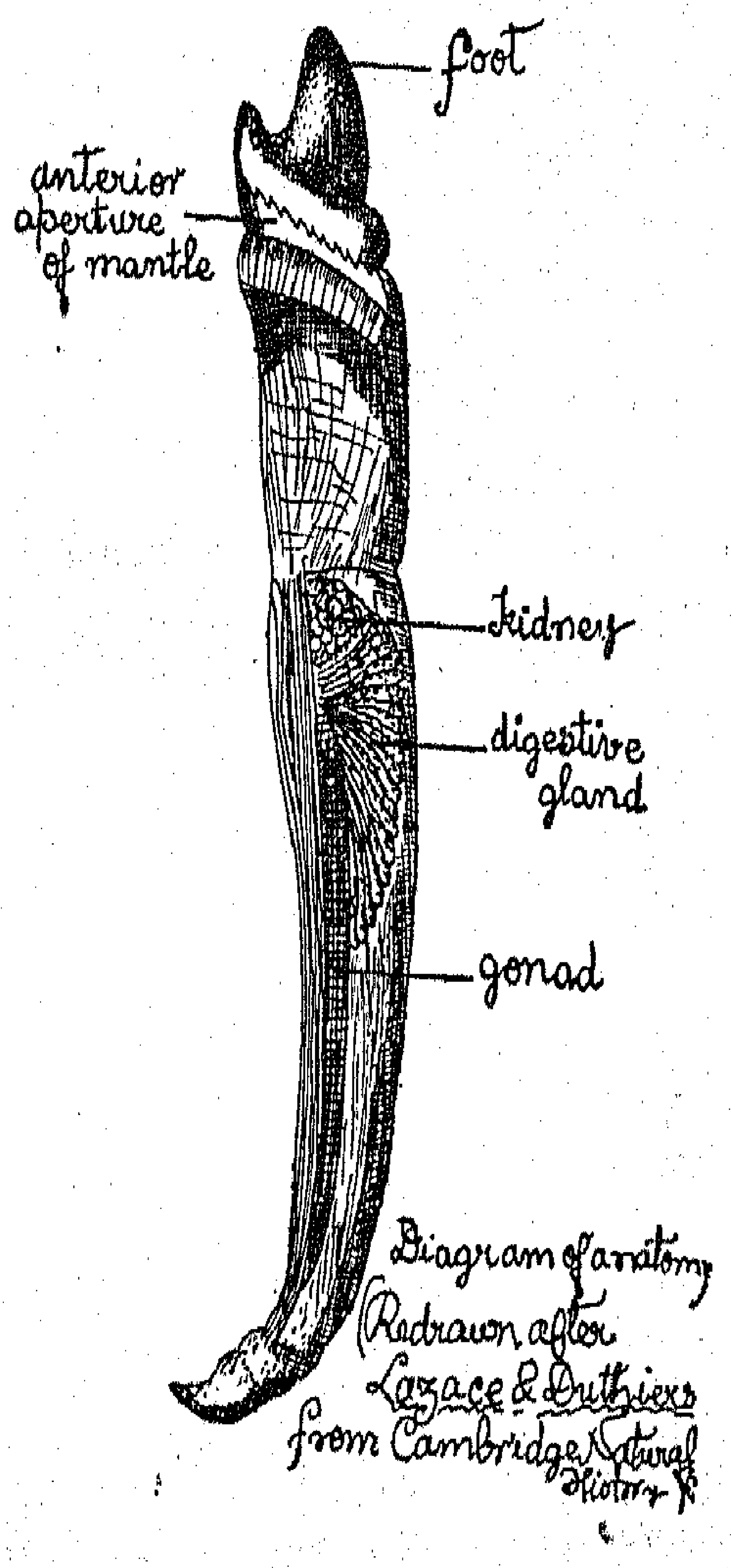


Fig. 313. Dentalium.

Dentalium (Elephant tusk) has a conical foot adapted for digging; from the dorsal side of its head arise extensive sensory filaments known as *captacula* which have sucker-like ends and which are also of use in seizing the prey. *Dentalium* is marine and lives in shallow waters up to the depth of 15000 feet and remains partly buried in mud or sand. The shell is tubular, broader at one end and thinner at the other end; the food and respiratory water-current is drawn in through the narrower end and leaves by the same end.

Class IV. **Pelecypoda** (Lamellibranchiata) are bilaterally symmetrical and compressed from side to side; the body is completely covered by the bilobed mantle, each of its two equal lobes secretes shell valve. The two valves of the shell are united on the dorsal side by a ligament and a hinge. Ventrally the two valves can be closed by means of adductor muscles. The head is rudimentary and has no eyes and tentacles. The *mouth* is situated between a pair of *labial palps*. Radula is not found. The foot is ventral, assists in locomotion in mud or sand. The mantle cavity has a pair of structurally complex *ctenidia* which bear cilia; these cilia and the palps help in securing minute fragments; the animals are unisexual.

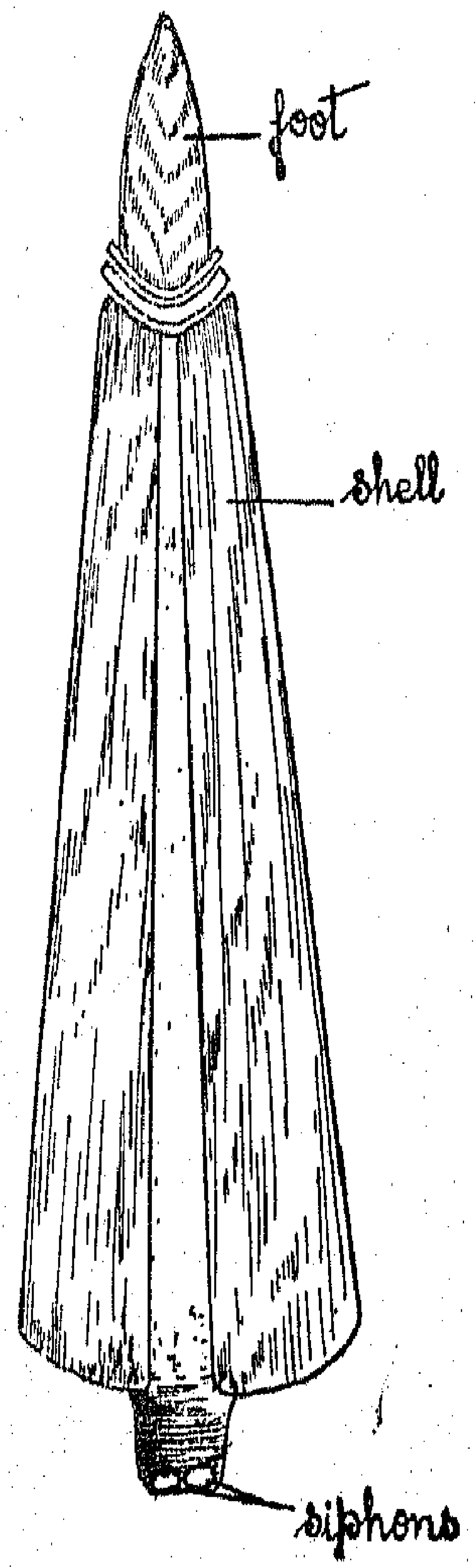


Fig. 314. Solen.

Solen (Razor fish); the two shell valves are equal, the foot is long powerful and cylindrical and is used for burrowing. The mantle is fused and the two siphons are long and united. The ventral valve is also united. The inhalant and exhalant siphons are long. The shell valves always remain open and cannot be closed by contraction of adductor muscles. The animal lives in sea and burrows in mud. It moves by jerking forward by sudden movements of the foot and ejecting water through the siphons.

Pecten (Scallop) is found free and is capable of swimming. The two valves are unequal, the right valve is larger and more complex. The animal rests on the right valve. The animal swims by opening and closing the valves rapidly and forcing out water between them. A single large adductor muscle which is present is divided into two unequal parts; it is the larger part which brings about swimming movements by rapid contractions. The foot is much reduced. The animal is hermaphrodite. All round the mantle there is a large series of stalked *ocelli*. *Pecten* is very active and swims swiftly by the flapping movements of the two shell valves.

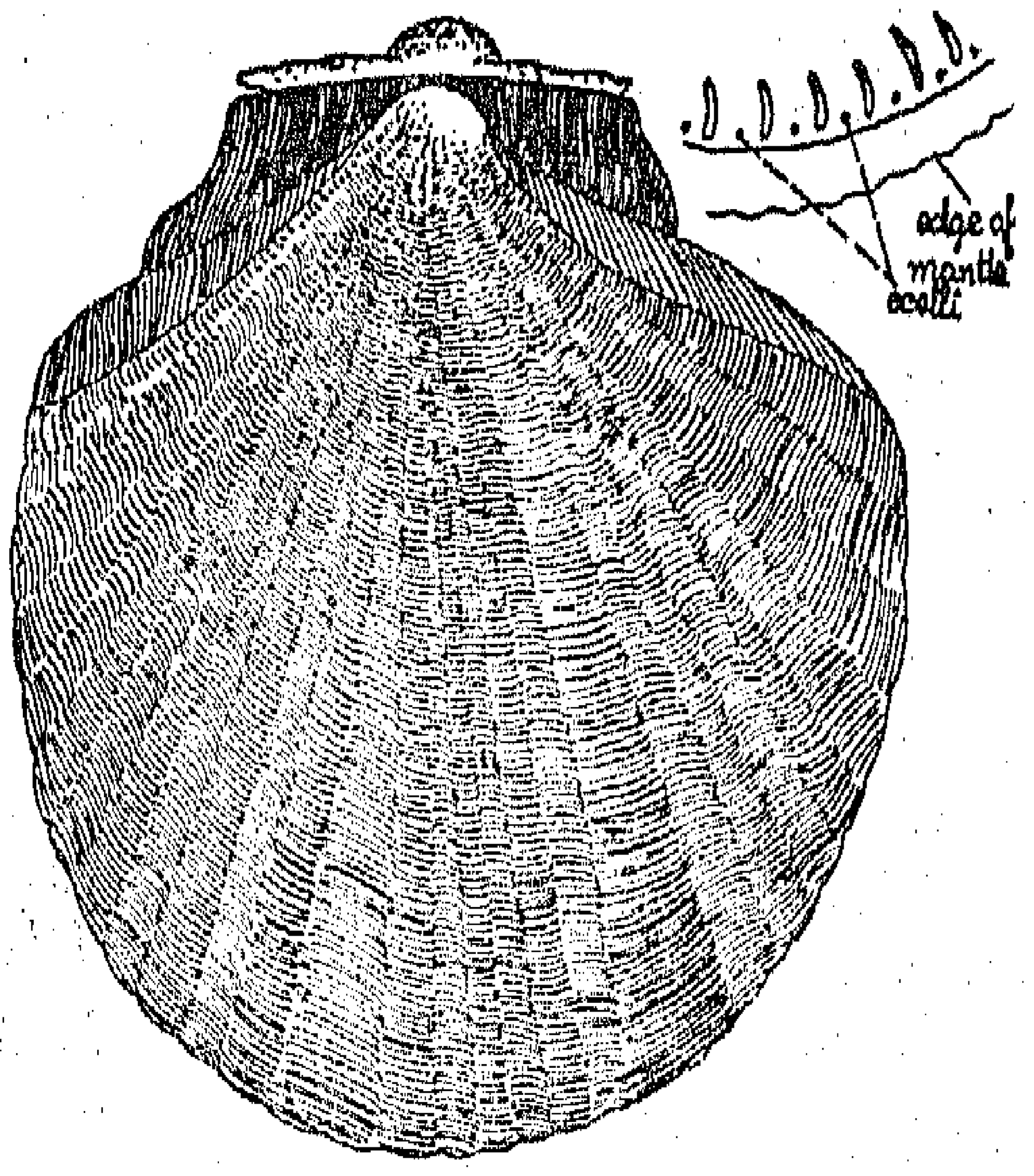


Fig. 315. Pecten.

Teredo (Shipworm) buries itself in the wood of ship. The two valves of the 'worm' are reduced and lie at the anterior end; they are used in boring through the wood. *Teredo* can digest cellulose and hemicellulose due to special enzymes. The boring in wood is accomplished by the downward and inward movements of the two shell-valves. The body is long and cylindrical and it secretes a calcareous tube round itself which can be detached. The siphons are long. The foot is very much reduced. The ctenidia are elongated and greatly modified. A ciliary water current enters into and exits from the mantle cavity. The animal mainly subsists on the carbohydrates of wood which also has traces of proteins. *Teredo* is reported to be capable of excavating long cylindrical tunnels in the wood of ship with remarkable rapidity: about a foot in a month. The wood becomes reduced to sawdust which, after being swallowed is ingested by the epithelial cells of the digestive gland. The body is held in position by the sucker like feet.

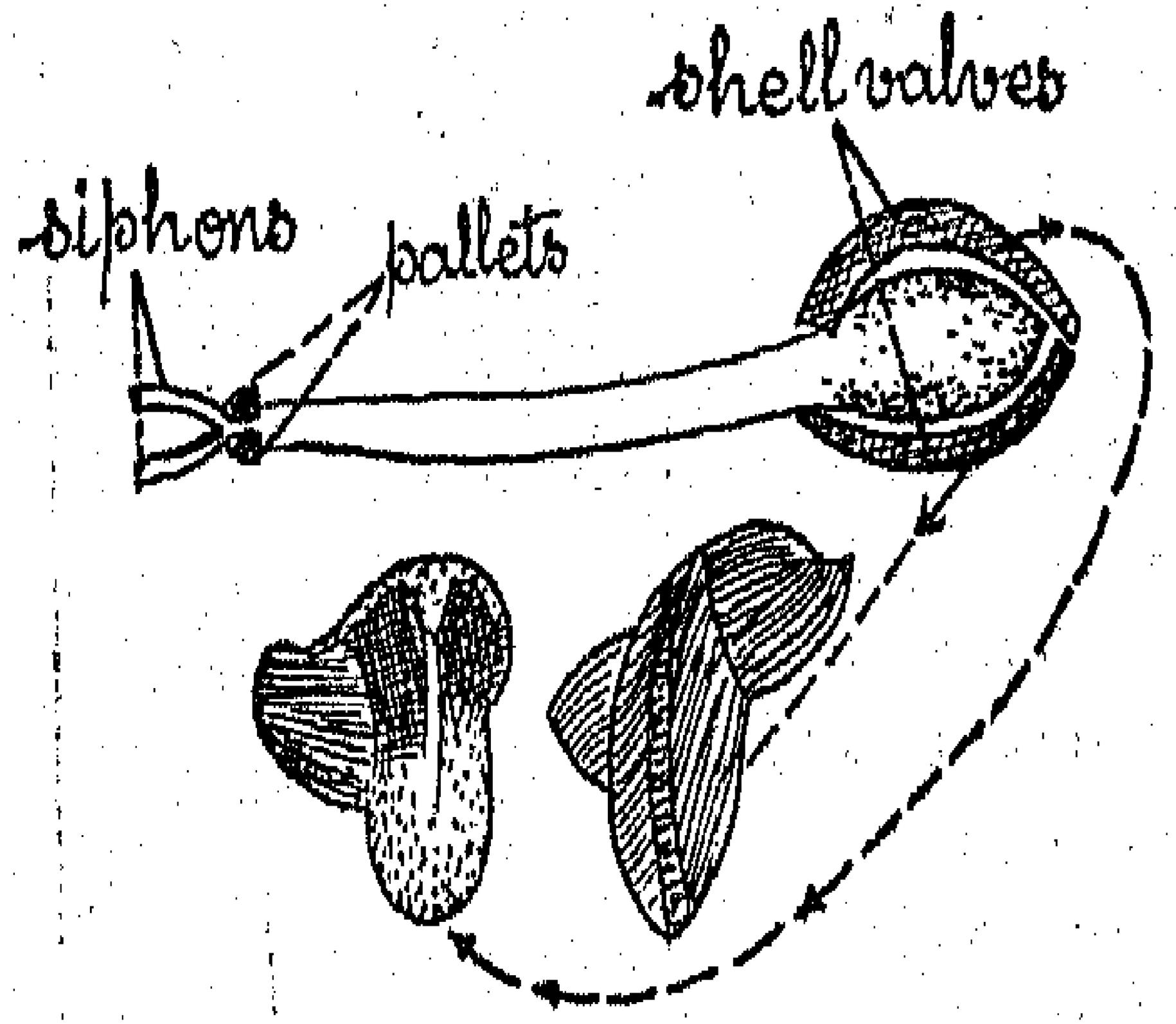


Fig. 316. Teredo (Shipworm).

Class V. **Cephalopoda** include bilaterally symmetrical forms with a well developed head bearing large eyes. The head is surrounded by a set of mobile and prehensile tentacles which are said to be the modified part of the foot. The foot forms a muscular funnel or siphon through which water from the mantle cavity is expelled. *Ctenidia* are one or two pairs. The genital part of the coelom communicates with the pericardial part. The visceral mass is not coiled, it is symmetrical.

The mantle encloses towards the posterior and vental side, a spacious mantle cavity containing the ctenidia and the renal, reproductive and anal apertures. In the typical cases, the shell is chambered and the animal occupies the last chamber. In many cases there is no shell; in many the shell is reduced while many forms have an internal shell. The nervous system is highly developed and is greatly centralised, the principal ganglia being aggregated together around the oesophagus. The forms are unisexual. The eggs are rich in yolk and development is direct. In many cases there is an ink gland opening through a duct into the rectum. The ink gland secretes a dark fluid. An ink gland is not found in *Nautilus* in which the shell is very well developed into which the whole animal can be withdrawn. The class includes the cuttle-fishes, Squids, Octopods and Nautili. The anterior portion of the foot is modified into arms or tentacles while the posterior portion of the foot is modified to form a *funnel* or *siphon* which leads out from the large mantle cavity and serves for the egress of water from the mantle cavity. The class is divided into two orders: I **Dibranchiata** having a single pair of ctenidia and kidneys; shell is internal and is enveloped by the mantle which may be reduced to a greater or lesser extent; there are 8 to 10 tentacles; complex eyes are present and the chromatophores are +; II **Tetrabranchiata** having a well-developed calcareous shell; two pairs of ctenidia and kidneys present in the existing forms; numerous arms without suckers; no chromatophores, eye simple; funnel in two halves.

Order I. **Dibranchiata.**

Suborder—**Decapoda** (Well developed coelom, ten arms, bearing stalked suckers; internal shell well developed). *Sepia.*

Sepia (Cuttle-fish) is marine, swims rapidly keeping its long axis horizontal. The mouth is surrounded by the bases of ten arms which occur in 5 pairs. The inner flat surface of all the arms except the 4th is beset with suckers arranged in four longitudinal rows. The shallow cup-like muscular suckers applied on any surface serve for adhesion on the 'partial vacuum' principle. The 4th pair of arms or *tentacles* are longer and narrower than all others and bear suckers only at their club like free ends. In male, the 5th arm on the left side at the base is slightly modified and on this place some of the suckers are absent. This hectocotylized arm acts as an intromittent organ. In *Sepia*, hectocotylization is only slight. There is a constricted neck and an elongated shield shaped trunk. A hard internal shell is present in the anterior region of the shield. A pair of large highly-developed *eyes* are present on the *head*, which is very distinct. The trunk is covered over by mantle which forms a rounded lobe anteriorly under which the head can be retracted to some extent. Towards the oral end, the mantle forms a ridge round the neck which on the posterior side forms the lip of the slit-like *pallial aperture* which leads into a large mantle cavity. Through this aperture, water is drawn in. There is a wide cleft between the posterior surface of the body and the oral edge of the mantle and this cleft leads into the mantle cavity. On the oral side of this cleft is found the large *funnel* which opens behind the neck and which also communicates with the mantle cavity. Through it water, excretory and genital products etc. are expelled out; it also has an important role in locomotion due to jects of water forced out through it. Water cannot enter through the funnel due to valvular arrangement. The right and left margins of the trunk have a thin muscular fold, the fin which helps in swimming. The internal shell which is leaf-like and bilaterally symmetrical is enclosed in a sac of the mantle. The shell gives support to muscles and is protective in function. In the integument, all over the surface are found chromatophores due to which the animal shows frequently changing colours. A pear shaped ink sac is present below the integument of the anterior wall. It secretes a black substance, '*ink*' which is discharged into the rectum and is then discharged in the mantle cavity on some alarm or 'danger'. The dark water (dark due to ink) which is expelled out through the funnel hides the animal and saves it from danger. There are two ctenidia in the mantle cavity. Of the sense organs, there are eyes and the statocyst. A pair of kidneys+. The animal is unisexual.

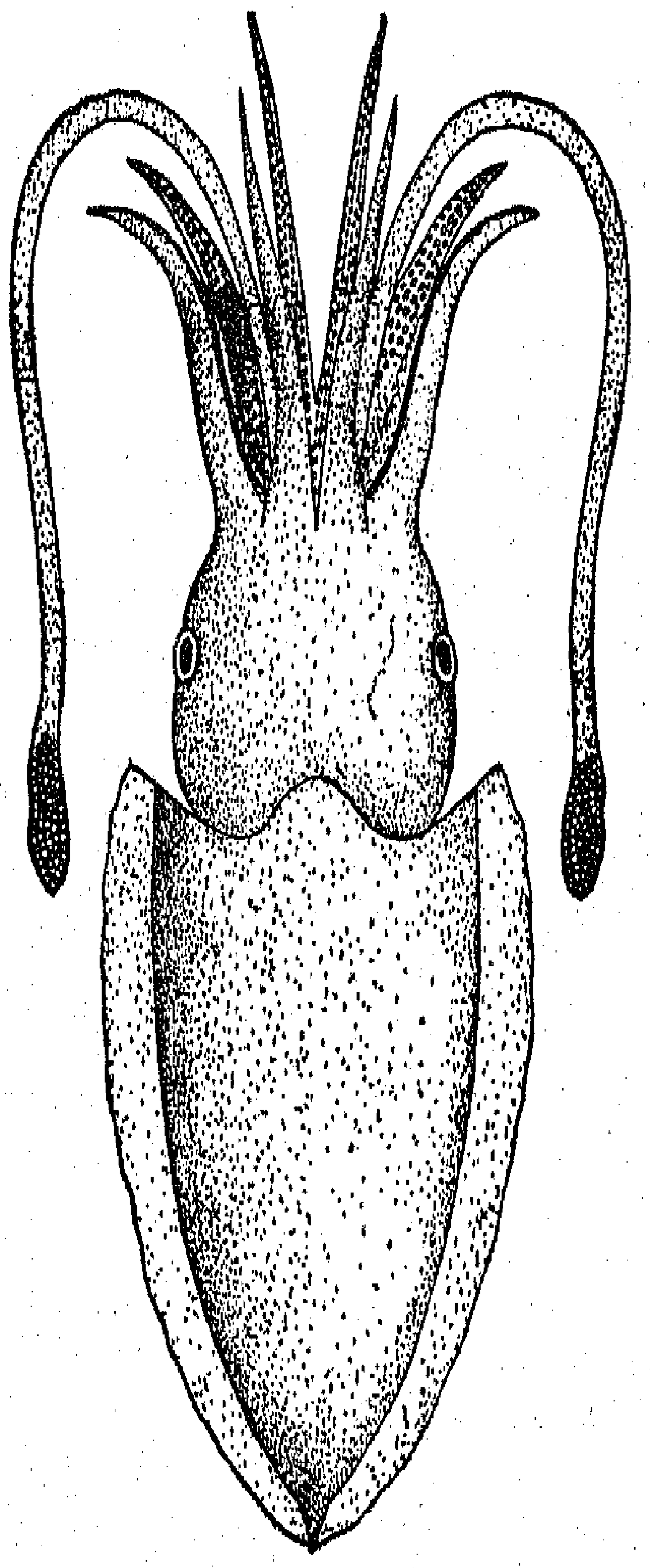


Fig. 317. Sepia (Dorsal view).

Sub order 2. **Octopoda** have eight arms with sessile suckers; the internal shell is vestigial or may be absent. Coelom is reduced. *Octopus* hides itself amidst stones and hunts prey only during nights. The shell is vestigial and the muscles are connected to it. Distinct ganglia are found in the nervous system.

Order II. **Tetrabranchiata** have four ctenidia (two pairs), four kidneys and four auricles. A well-developed external calcareous shell is present; the shell is coiled in a plane spiral. Ink gland and chromatophores are absent. Arms are very nemerous and bear no suckers. The eyes are simple and the funnel has two valves. *Nautilus*.

Nautilus is the only surviving cephalopod with an external shell. The *shell* is coiled in a plane spiral; internally it is divided by septa into a series of chambers. The body occupies the last and the largest chamber and the rest of the chambers are filled with gas. The middle of all the septa is perforated and through these successive perforations a spiral tube, the *siphuncle* passes which is continuous with the viseral hump. By means of the gas (which has lesser oxygen than that in air) contained in other chambers the heavy shell is buoyed up in the water and the animal can swim easily. The gas is probably secreted by the siphuncle. The head foot is produced into two circles of very numerous retractile arms which lack suckers. The anterior part of the head forms a hood which acts as an operculum when the animal is retracted. The funnel composed of two halves is really a modified portion of the head foot. The earliest formed portion of the shell was membranous and is now represented by a small space in the centre.

Nautilus is found on some tropical coasts where it swims near the bottom and sometimes crawls over the rocks. It has a nocturnal and gregarious habit. It is the sole living representative of the many caphalopods which had external chambered shells which flourished between the earliest Cambrian and the late Cretaceous periods (i. e. *about* 400 to 500 millions of years back); they were a dominant invertebrate group during the Mesozoic (120 to 180 millions of years back) but then died out suddenly leaving only *Nautilus.* The entire Cephalopoda represented today have internal shells with the exception of *Nautilus*. Besides, *Nautilus* differs from the other living representatives of Cephalopoda in: (i) possessing 4 ctenidia, 4 kidneys without renopericardial openings, (ii) having simple reduced eyes which have no lens (the animal is nocturnal) and (iii) in having no ink sac.

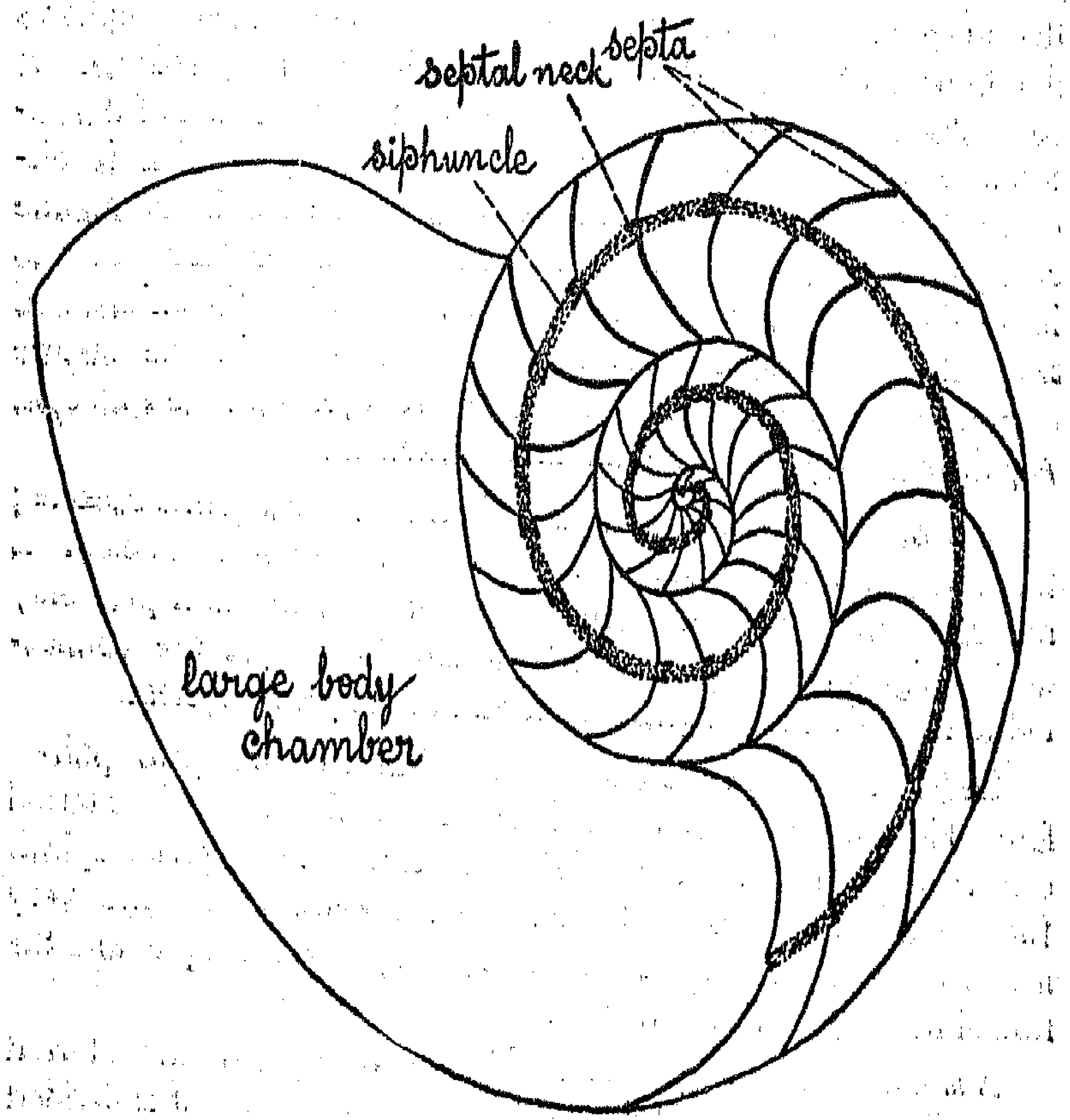


Fig. 318. L. S. empty shell of Nautilus.

51

The Echinodermata-Digestive, Water-Vascular and Locomotory Systems—Pedicellariae

The phylum **Echinodermata** comprises spiny skinned coelomate animals exhibiting radial symmetry in the adult condition although the larvae are bilaterally symmetrical. All echinoderms are marine and generally have a pentamerous arrangement of parts.

Digestive System of Starfish

In the centre of the oral surface is found a five-rayed aperture, the *actinostome.* Within the pentagonal octinostome lies a space, the *peristome* which is covered with soft integument. In the centre of the peristome is found a circular opening, the *mouth.*

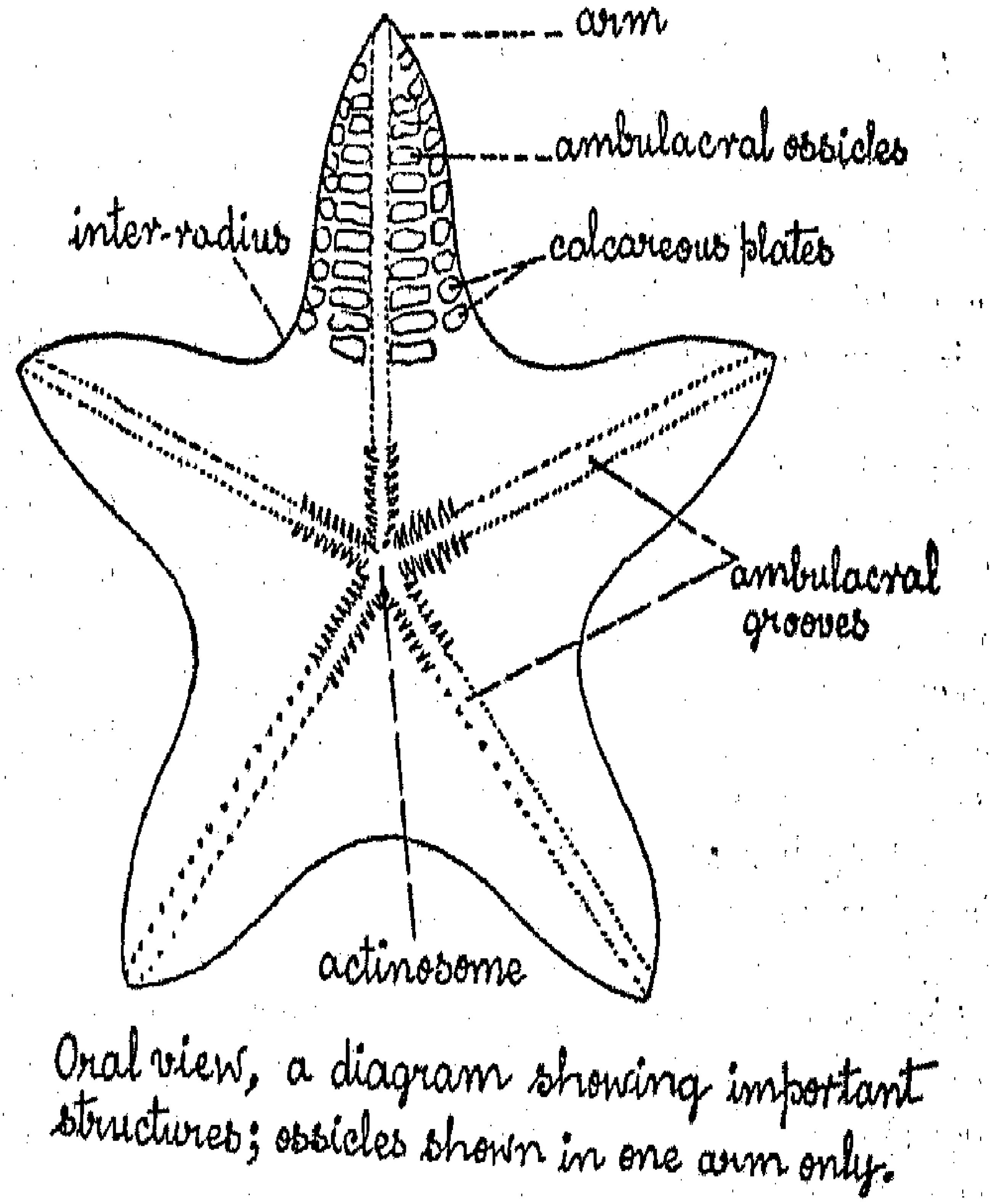

arm
ambulacral ossicles
inter-radius
calcareous plates
ambulacral grooves
actinosome
Oral view, a diagram showing important structures; ossicles shown in one arm only.

Fig. 319. Oral view of Pentaceros Read 'actinostome' for 'actinosome' in the label.

The mouth leads into a short passage, the *oesophagus.* The oesophagus leads into a five lobed wide-sac, the *cardiac stomach.* The five lobes occur opposite the five arms. The walls of the cardiac stomach are greatly folded. It is remarkable that *the entire*

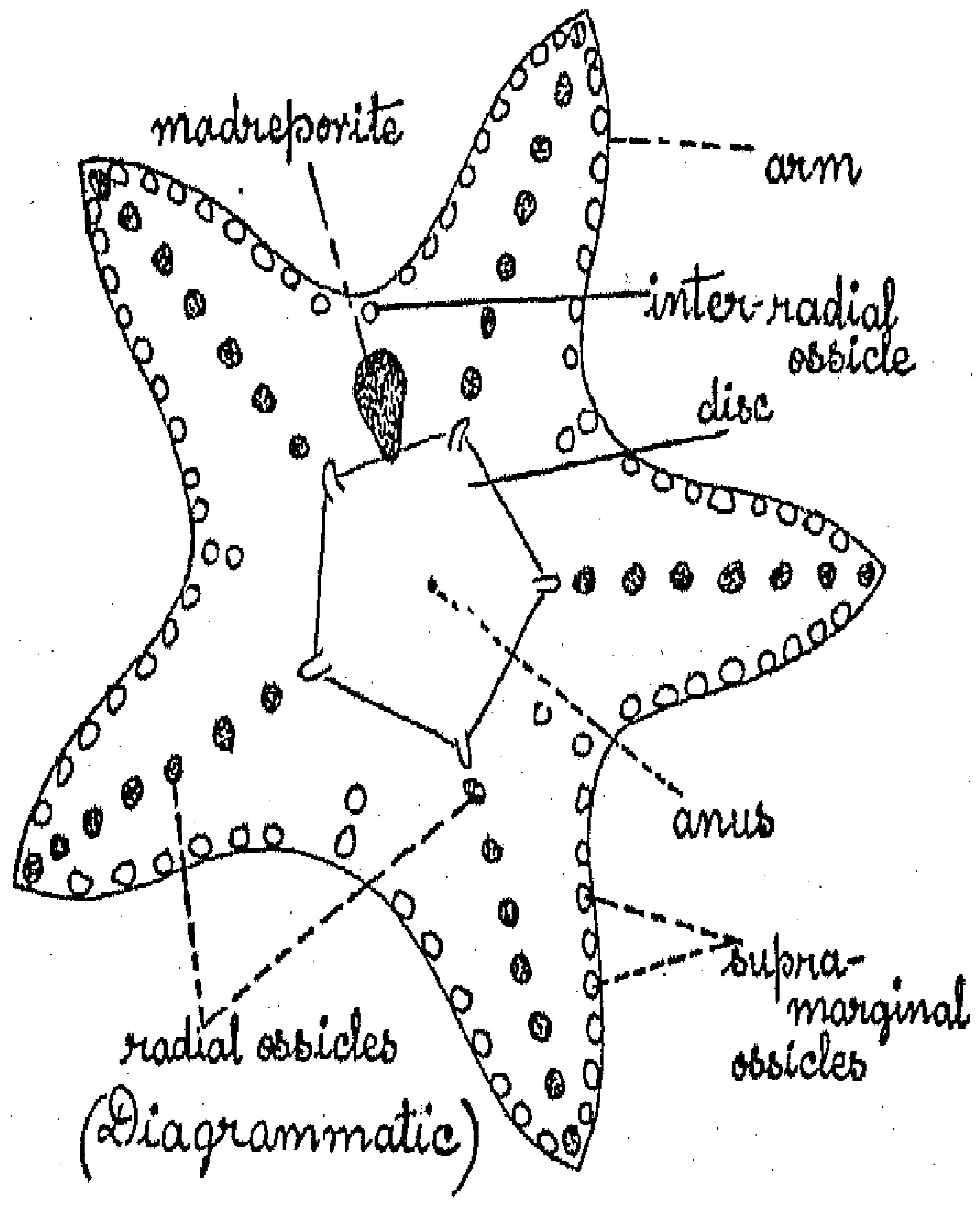


Fig. 320. Aboral view of Pentaceros.

cardiac stomach can be everted out through the mouth opening. The eversion is brought about by the contraction of muscles of the body-wall. The retraction is brought about by the retractor muscles arising from the sides of the ambulacral ridges.

The cardiac stomach opens aborally into the *pyloric stomach* which is also pentagonal but which is much smaller than the cardiac portion. At each angle from the pyloric portion arises a cylindrical duct which soon divides into two long hollow *caeca* which run through the entire length of the arm. Each of the five arms has a pair of such hollow stems or the *pyloric caeca.* Each of these sends out on its sides two series of short branches each of which is connected which small pouches. The **pyloric caeca** are attached to the aboral wall; they are considered as digestive glands. The digestive secretion of the pyloric caeca contains enzymes which digest carbohydrates, porteins and fat. Thus the secretion of the pyloric caeca appears to correspond to that of the vertebrate pancreas. The pyloric division of the stomach opens into a very short *intestine* which gives off in each inter-radius two hollow *intestinal caeca.* The intestinal caeca have short branches of an irregular shape. The intestine opens by the *anal aperture* nearly at the centre on the aboral side.

Animals of any kind which can be seized serve as *food* of the star-fish: these usually consist of fish, oysters, mussels, clams, barnacles, snails, crustaceans and worms. Certain species seize the bivalves by means of their arms, pull them open with their tube-feet and then evert out their cardiac stomach over the soft parts of the mollusc.

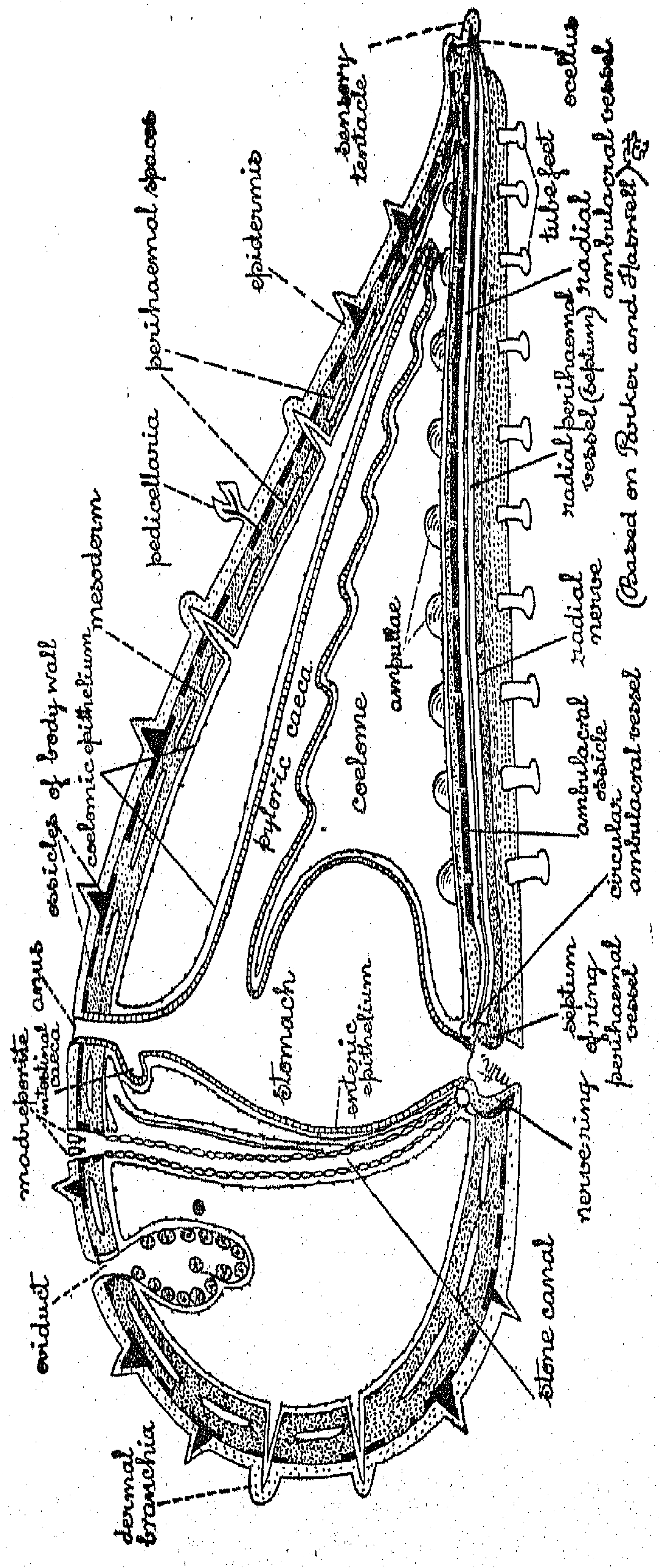


Fig. 321. Diagrammatic section through the disc and an arm of the starfish.

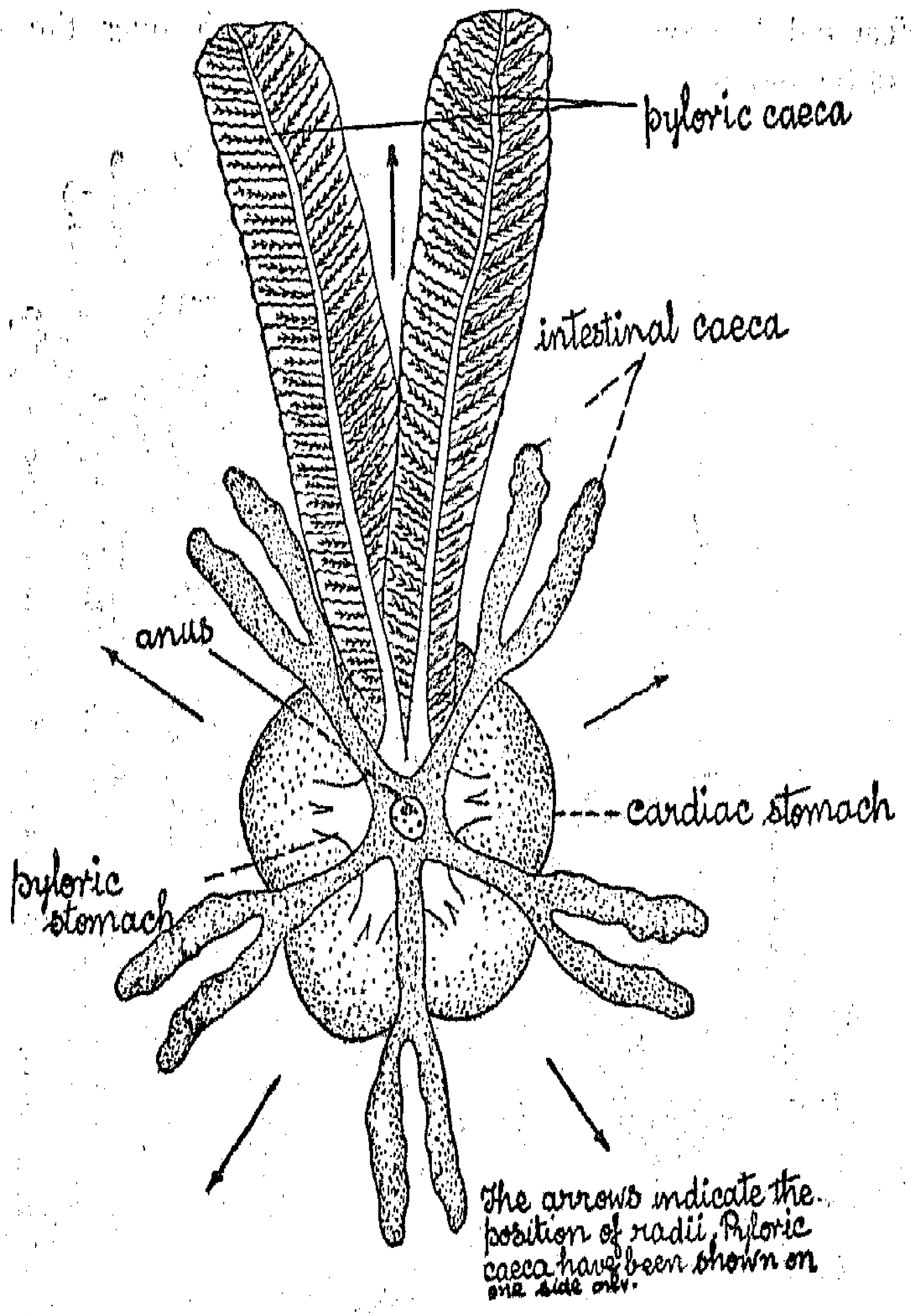
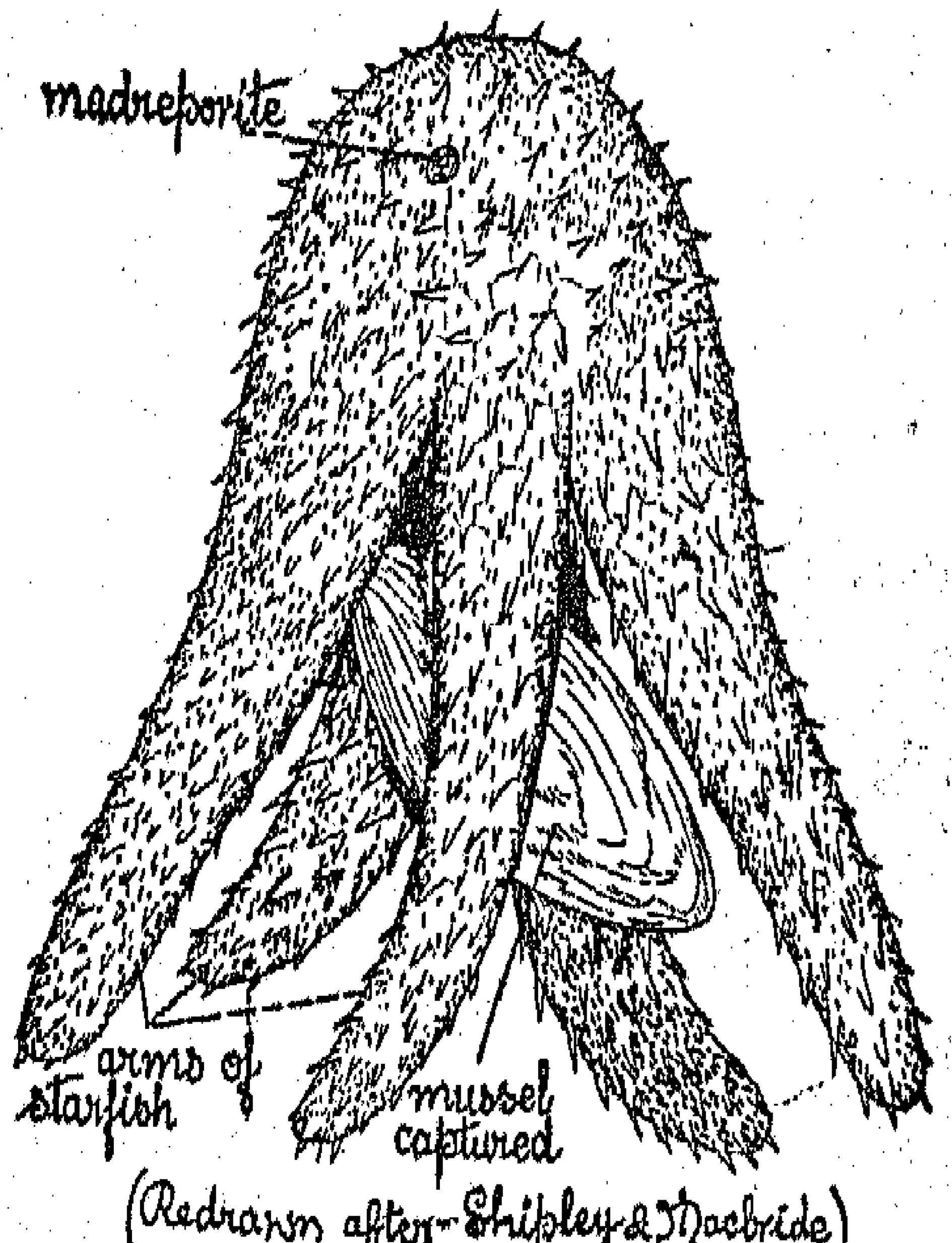

pyloric caeca
intestinal caeca
anus
cardiac stomach
pyloric stomach
The arrows indicate the position of radii. Pyloric caeca have been shown on one side only.

Fig. 322. A diagram showing the parts of the alimentary canal in an upper view.



(Redrawn after Shipley & Macbride)

Fig. 323. A mussel being devoured by the starfish.

The mussel is seized by the tube-feet. The arms of the starfish are folded over it like an umbrella and the prey is placed under the mouth. The everted stomach is then wrapped over and round the prey. The mussel is forced to gape its valves. The starfish then applies the everted stomach on the soft parts of the prey and digests it completely, leaving its empty shell. The prey digested outside forms a broth which is then ingested. The lining of the stomach secretes mucus. The ferments secreted by the pyloric stomach and the pyloric caeca, convert proteids into diffusible peptones, starch into maltose and facts into fatty acids and glycerine. The star-fishes are voracious feeders. They are destroyed from the oyster beds by various means to avoid damage to the oysters.

The Water-vascular System of Starfish

The water vascular system is a system peculiar to the phylum. The system represents one of the divisions of the coelom and consists of the following parts: *madreporite, stone canal, ring vessel, ambulacral vessels, lateral canals, tube feet, Teidmann's vesicles, and Polian vesicles.*

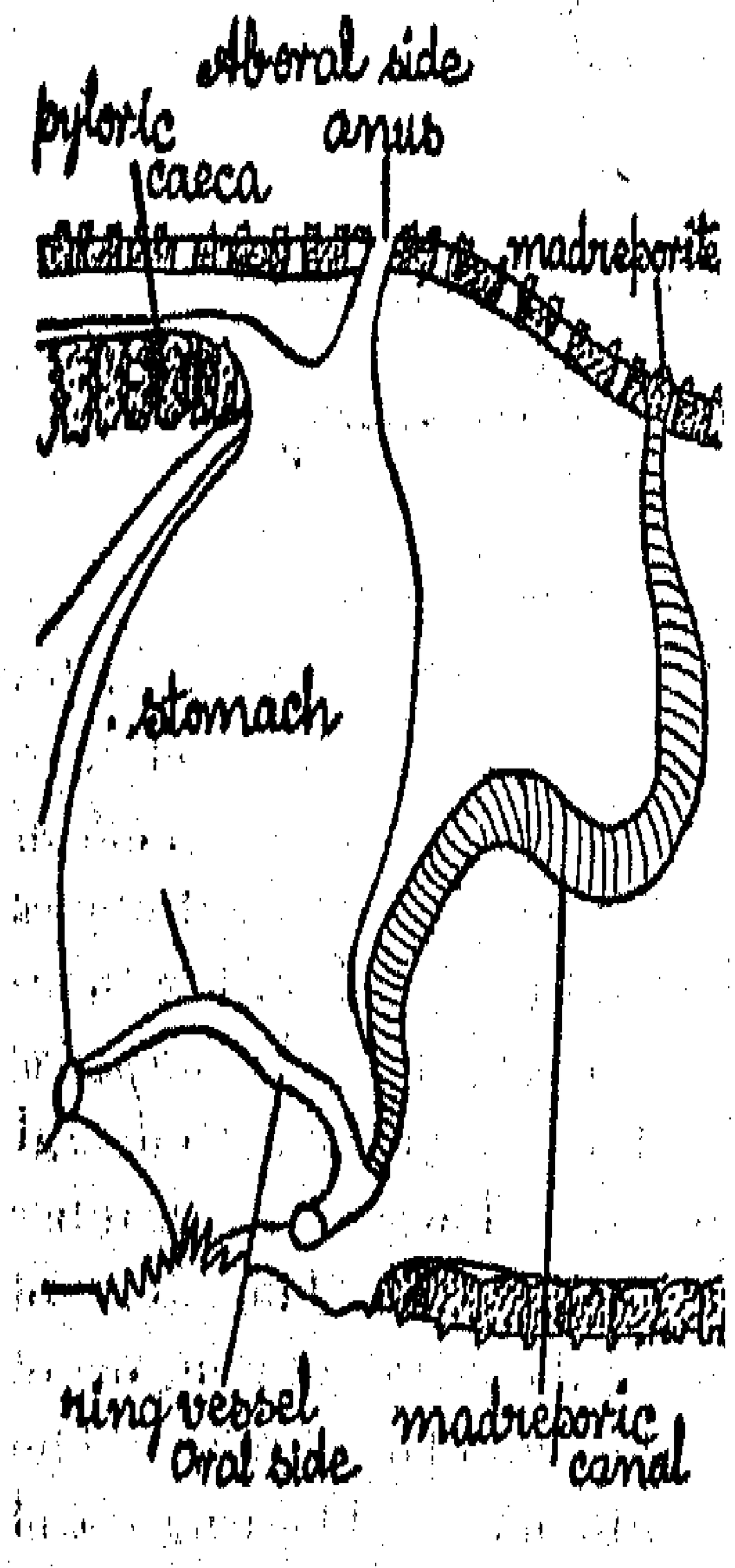


Fig. 324. Diagram to show the position of the madreporic canal.

The *madreporite* is a flat, nearly circular calcareous plate, situated on the aboral surface between the bases of two of the arms which are termed as the *bivium.* The surface of the madreporite bears a number of narrow straight or wavy grooves. At the bottom of these grooves are found numerous pores each leading into a *pore-canal* which runs inwards in the thickness of the madreporite. The pore canals unite to form collecting canals.

These collecting canals open into an *ampulla* beneath the madreporite. Running downwards from this ampulla is found a *madreporic* or *stone canal.* The stone-canal proceeds downwards towards the oral surface. The walls of the stone canal are calcareous. The *stone-canal* is an S-shaped cylindrical canal. A series of calcareous rings support the walls of the stone canal. In case of *Asterias* and *Pentaceros,* projecting into the stone canal is a ridge which bifurcates in two spirally coiled lamellae which occupy a large portion of its lumen. At the oral end, the stone canal is free from the calcareous matter. The *grooves* of the madreporite, the *pore-canals* and the *madreporic canal* are all lined with long cilia.

At the oral end the stone canal opens into a five sided ring canal, the *ring vessel* of the *ambulacral system.* From this ring vessel, arise five *radial ambulacral vessels*, each running the length of the arm right up to the extremity of the arm where it terminates in the lumen of the *terminal tentacle.* The ambulacral vessel gives off on each side *lateral canals* which join the tube feet. Each *lateral canal* divides into two portions which are disposed at right angles to *it* ; one of these portions dilates to form the *ampulla* of the tube-foot, while the other forms the tube-foot proper. The *ampullae* are bladder-like bodies arranged on the side of the ambulacral ossicles in a double row, one higher and one lower. Each tube-foot corresponds to one of the ambulacral pores. The cavity of the tube-foot communicates with that of the *ampulla* by means of a narrow canal which runs through the ambulacral pore. The ampullae and the tube feet are highly muscular. The ring vessel and the ambulacral vessels are lined with *ciliated coelomic epithelium.*

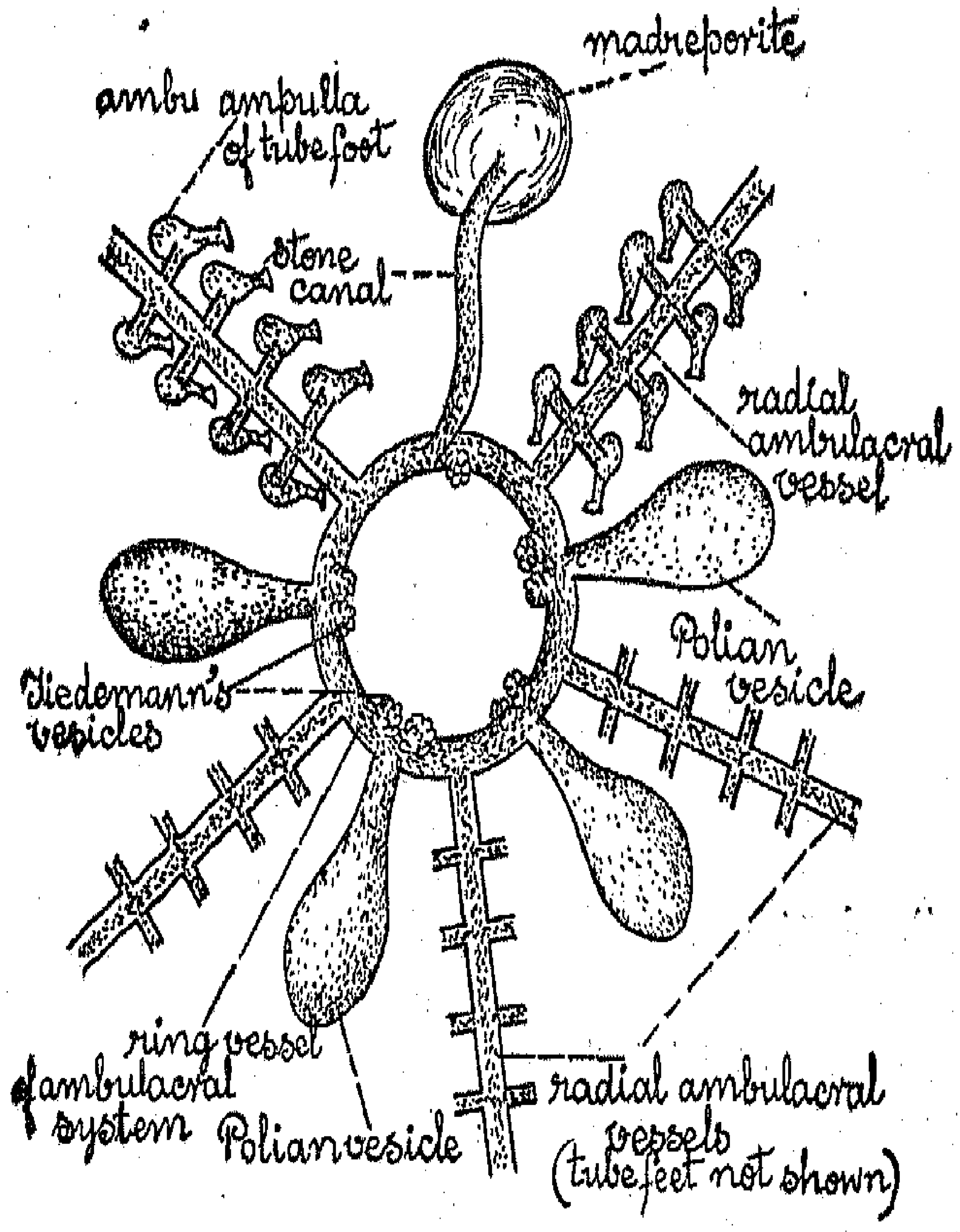


Fig. 325. Diagram of the water vascular system.

On its inner side, the ring vessel gives off in each inter-radius, a pair of little rounded hollow glandular bodies, the *Tiedeman's vesicles.* (In the inter-radius containing the madreporic canal there is only one Tiedemann's vesicle. In all, there are *only nine* Tiedemann's bodies). Their cavity is divided into a number of chambers with highly folded walls. Their walls bud off amoeboid cells and their lumen contains coelomocytes and a coagulated fluid. The amoebocytes produced, pass into the fluid of the water vascular system.

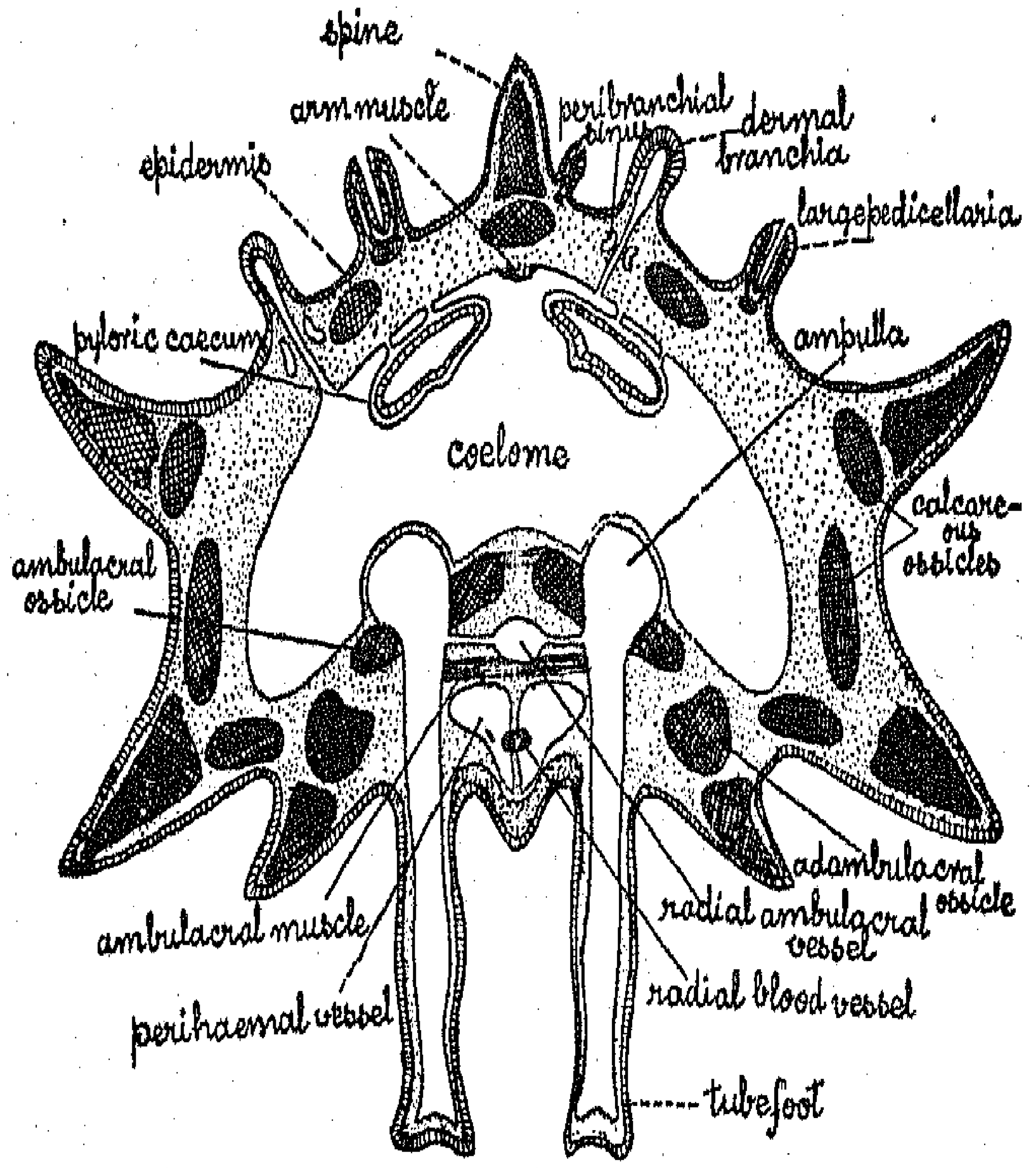


Fig. 326. Transverse section of an arm of starfish (Diagrammatic) (Based on Borradaile and Potts)

From the five sided ring-vessel are given off inter-radially a series of five pairs of pear shaped appendages, the *Polian vesicles.* The *Polian vesicles* are large thin-walled bladders with narrow elongated necks. They keep the pressure of the water, constant in the radial canals and their walls also bud off amoeboid cells. Polian vesicles are not found in *Asterias.*

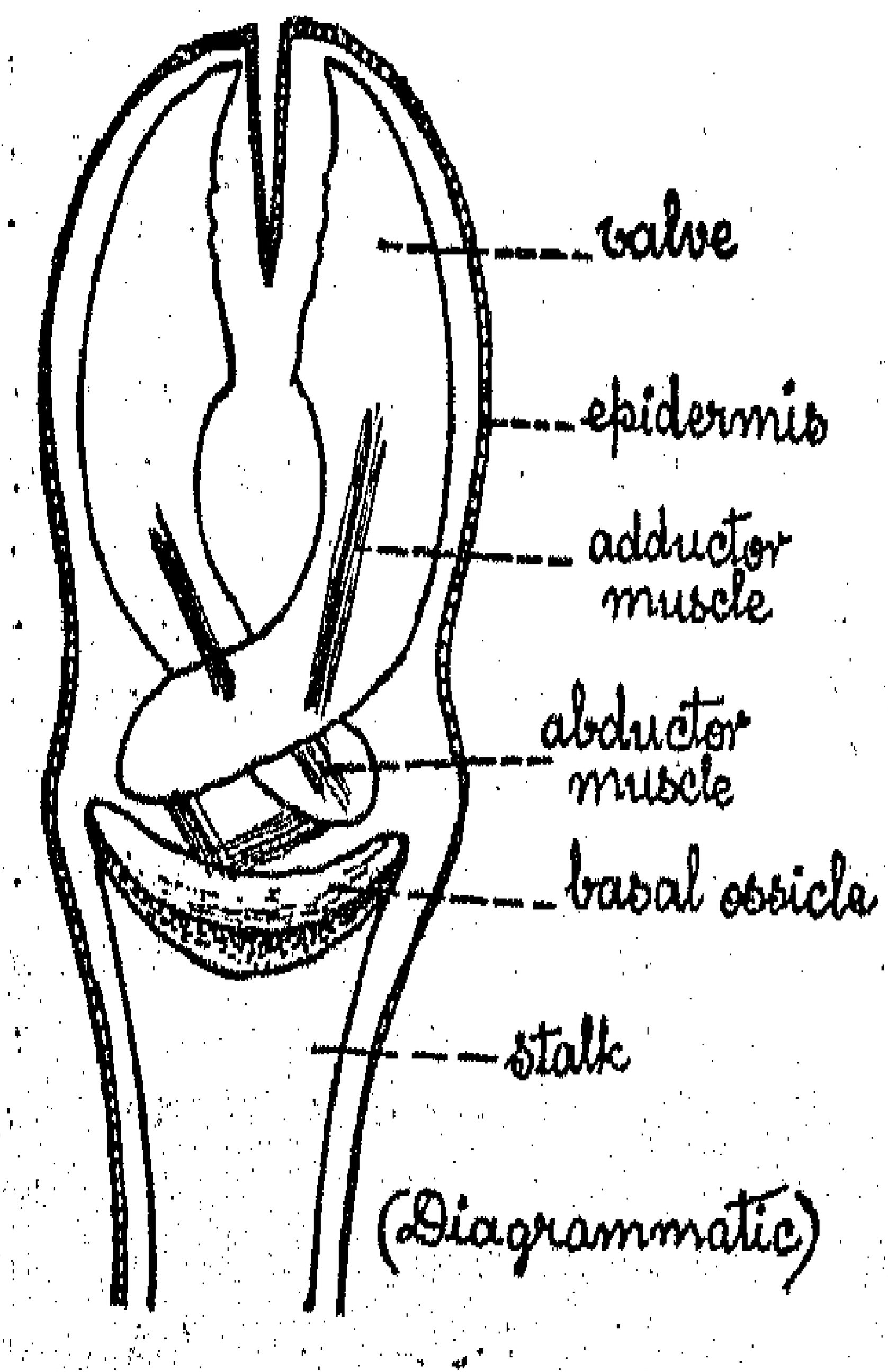
The entire water-vascular system has muscular walls and is lined with ciliated coelomic epithelium. The muscular layer is well developed in *ampullae* and *Polian vesicles* but it is most pronounced in the tube-feet.

Due to the beating of cilia of the stone canal, a pressure is maintained in the coelomic canals of the water vascular system. The canals of this system end blindly in the cavities of the tube-feet. Water is driven outwards through the walls of the tube-feet by the pressure behind ; this is brought about by the contraction of the muscles in the walls of the ampullae.

The **water vascular system** is *mainly responsible for locomotion* which occurs by tube-feet. The system functions by means of *hydraulic pressure.* The tube-fect also *play important role in the capture of prey* and in tackling the food. The tube-feet are also *sensory* : they are *tactile* and some of them are *olfactory.* The water-vascular system is filled up with an albuminous fluid in which float the amoebocytes. A slight excretory function has also been suggested because of the diffusion of dissolved wastes through the walls of the tube-feet.

Locomotion.—Locomotion is brought about by the *podia* or *tube-feet* which are the outpushings of the water vascular system having sucker like extremities. The star-fish slowly creeps by the *tube-feet* (which are distensible finger-like protrusions of a part of the coelom) arranged in a double alternating row on each side of the ambulacral grooves. The muscles running round the ampulla contract due to which the ampulla contracts; the fluid contained in the ampulla is driven downwards and is injected into the tube-foot which gets distended. The broad flattened extremity of the distended tube-foot is brought in contact with the surface of the substratum and is pressed against it. The tube-feet are extended outwards and forwards and get fixed on the surface of the substratum by the suckers. Then, the longitudinally arranged muscles of the tube-foot resume action with the result that the whole tube-foot contracts so as to draw the body forwards (i. e. in the direction of locomotion). The sucker then relaxes its hold and the tube-foot are stretched forwards again. The sequence of these stages results in a steady progress of the animal on the surface. The water-pressure in the water vascular system is so controlled that the end of the tube-feet can be made convex or concave. When against a substratum, the end of the tube-foot produces a concavity, the concave end of the tube-foot functions like a 'suction-cup'. When the concavity is relaxed and the end of the tube foot becomes convex, the suction is released. Locomotion occurs in the starfish by the attachment and release of the tube feet along with their extension and contraction.

Pedicellariae.—These are *microscopic calcareous structures* found attached to the spines and in between them on the oral surface and in the intervals between the spines of the aboral surface. The pedicellariae are modified spines and perform snapping movements due to special muscles attached to them. The pedicellariae of the starfish are of the following types :



← Fig. 327. Crossed pedunculate pedicellaria,

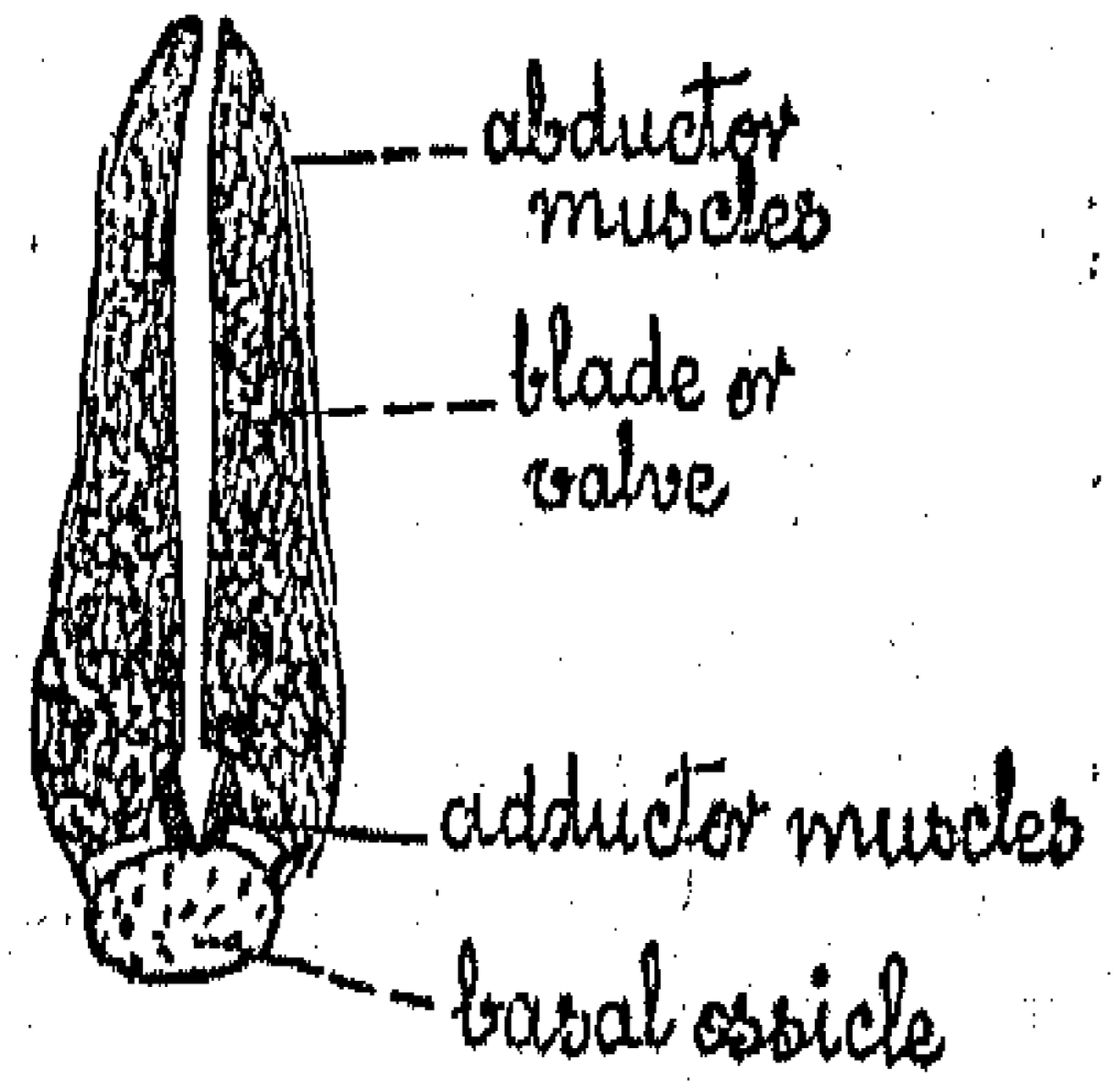


Fig. 328. Straight pedicellaria of Asterias.

(*i*) *stalked or pedunculate* / (*a*) with straight jaws
\ (*b*) with crossed jaws

(*ii*) *sessile*

(*iii*) *alveolar*

(*i*) The *stalked pedicellariae* consist of two jaws and a basilar piece. The jaws are movably articulated with basilar piece and can close and open due to muscles. Each pedicellaria is provided with two pairs of *adductor muscles* and one pair of *abductor muscles*. The adductor muscles close the jaws and the abductor muscles open them. The (*a*) *straight pedicellariae* operate like forceps and in the (*b*) *crossed pedicellariae* the two jaws when closed cross each other like scissors. The crossed variety is found largely on the aboral surface around the spines. The stalked pedicellariae are supported on a flexible stalk.

(*ii*) *Sessile pedicellariae* may consist of two or more movable spines attached directly to the skeletal ossicle by means of muscle fibres. In some of these pedicellariae, the blades are broader than long forming two valve-like pieces, such pedicellariae are known as valvulate.

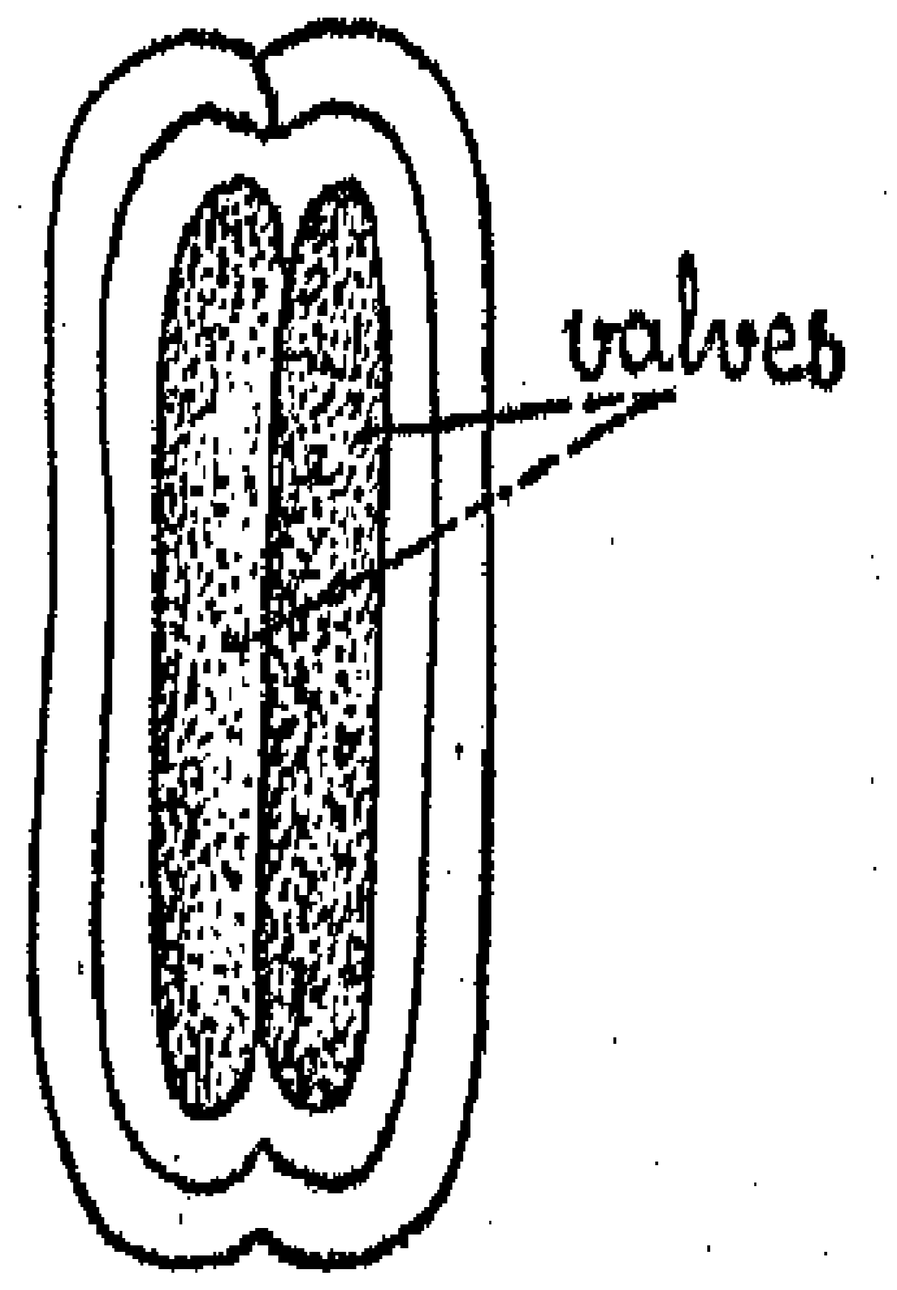


Fig. 329. Valvulate pedicellaria.

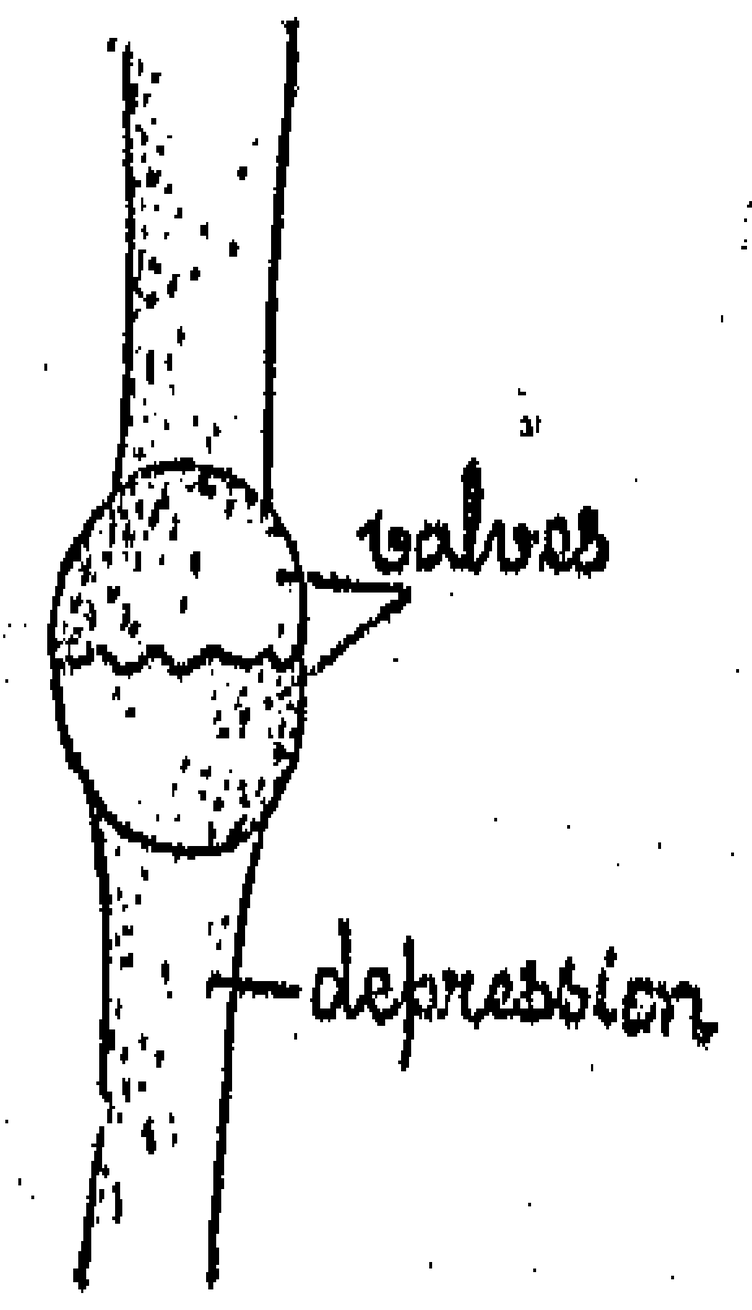


Fig. 330. Alveolar pedicellaria.

(*iii*) The *alveolar pedicellariae* are sunk in an alveolus or a pit in the skeletal calcareous plate; the pit serves for the attachment of the muscles which move the valves.

The pedicellariae are movable and are weapons of defence and offence; they can damage other organisms which come in contact with the surface of their skin. The pedicellariae also keep the skin clear of foreign growths and also serve to protect the *dermal branchiae* or *papulae*. On alarm, or touch with other animals, the blades of the pedicellariae are opened and held firmly upon any **projections of the prey,** seizing it in this manner.

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Classification of Echinodermata

1. Classify the phylum Echinodermata giving examples.

The phylum **Echinodermata** have the following characters:

(1) Radial symmetry+; it conceals a fundamental bilateral symmetry;

(2) The surface is covered with an exoskeleton of calcareous plates or ossicles which support a system of movable or immovable calcareous spines;

(3) a large body cavity or coelom+; well developed alimentary canal, nervous and vascular system+;

(4) a characteristic system of vessels: the *ambulacral system* is concerned in locomotion and other functions;

(5) the *tube-feet*: the distensible finger like appendages of the ambulacral system are the organs of locomotion, are contractile and elastic bodies;

(6) reproduction is entirely sexual;

(7) a peculiar bilaterally symmetrical larval stage is+; and

(8) all the Echinoderms are marine.

The phylum **Echinodermata**

Subphylum **I Eleutherozoa** (Free living echinoderms which have no stalk.)

Subphylum **II Pelmatozoa** (With a stalk composed of a row of ossicles.) Class 5 **Crinoidea**

Class 1 **Asteroidea** 2. **Ophiuroidea** **4.Holothuroidea**

Class 1 **Asteroidea** (Pentagonal star-shaped body: disc and usually 5 arms, each arm contains caeca of the alimentary canal and an extension of coelom, anus and madreporite on the aboral surface, open ambulacral grooves, tube feet have suckers, pedicellariae +, larva is a *bipinnaria* or a brachiolaria.

Order 1 **Phanerozonia** (Large marginal plates round the margin of arms and discs; dermal branchiae only on the aboral surface) *Pentaceros*, *Anthenea* etc.

Order 2 **Cryptozonia** (marginal plates small or absent, dermal branchial+on both surfaces) *Asterias*.

2. **Ophiuroidea** (Star-shaped body arms sharply marked off from the disc, caeca of gut not found in arms, tube-feet lack suckers, no pedicellariae, ambulacral grooves covered, madreporite found only on the oral side. The larva is a *pluteus*. *Ophiothrix* (Brittle-star) *Ophiura*.

3. **Echinoidea** Body, globular cushion shaped or discoidal; no arms, body enclosed in a shell or *corona* formed of closely fitting calcareous plates; no ambulacral grooves; on the surface, alternating ambulacral and inter ambulacral areas extend from one pole to the other; tube-feet are provided with suckers; long numerous spines and pedicellariae, larva is a *pluteus*. *Echinus* (Regular sea-urchin)

Class 5 **Crinoidea** Known as sea-lilies or feather stars, have branched arms (usually five). From the aboral pole springs the *stalk* used for attachment; oral pole directed upwards normally; madreporite, spines and pedicellariae absent. *Tube-feet* without suckers and ampullae and hence tentacle like. Ambulacral grooves are open and form food grooves radiating out from mouth along the oral surface of the arms *Antedon*.

4. **Holothuroidea** (Elongated body with 5 sides; muscular body wall contains spicules or small ossicles, spines and pedicellariae absent: arms absent, five ambulacral areas on the surface may or may not be distinguishable; adults lack external madreporite; a circlet of large oral tentacles represents modified tube-feet. Rest of the tube-feet have suckers; e. g. *Holothuria* (Sea cucumber).

A brief account of the important types

Class **Ophiuroidea**—*Ophiothrix* (or brittle-star)—The arms are sharply marked off from the disc upon which they are freely movable. The animal moves by pushing and pulling upon the surrounding objects with its arms. Locomotion does not occur by the tube-feet which are without ampullae and suckers. The arms are armoured with skeletal plates. On the side plates are found spines which facilitate grip. The ambulacral groove is covered with calcareous plates so that there is formed an epineural canal in which the nerve-cord lies protected. The caeca of the alimentary canal do not extend into the alimentary canal. The ambulacral ossicles of each pair fuse to form pieces known as *vertebrae* which can be moved upon one another in various directions. The vertebrae articulate by 'knob and socket' arrangement. No part of the alimentary canal can be everted through the mouth. There is no anus. The madreporite is on the oral side in the adult. The axial sinus, stone canal, axial organ etc.

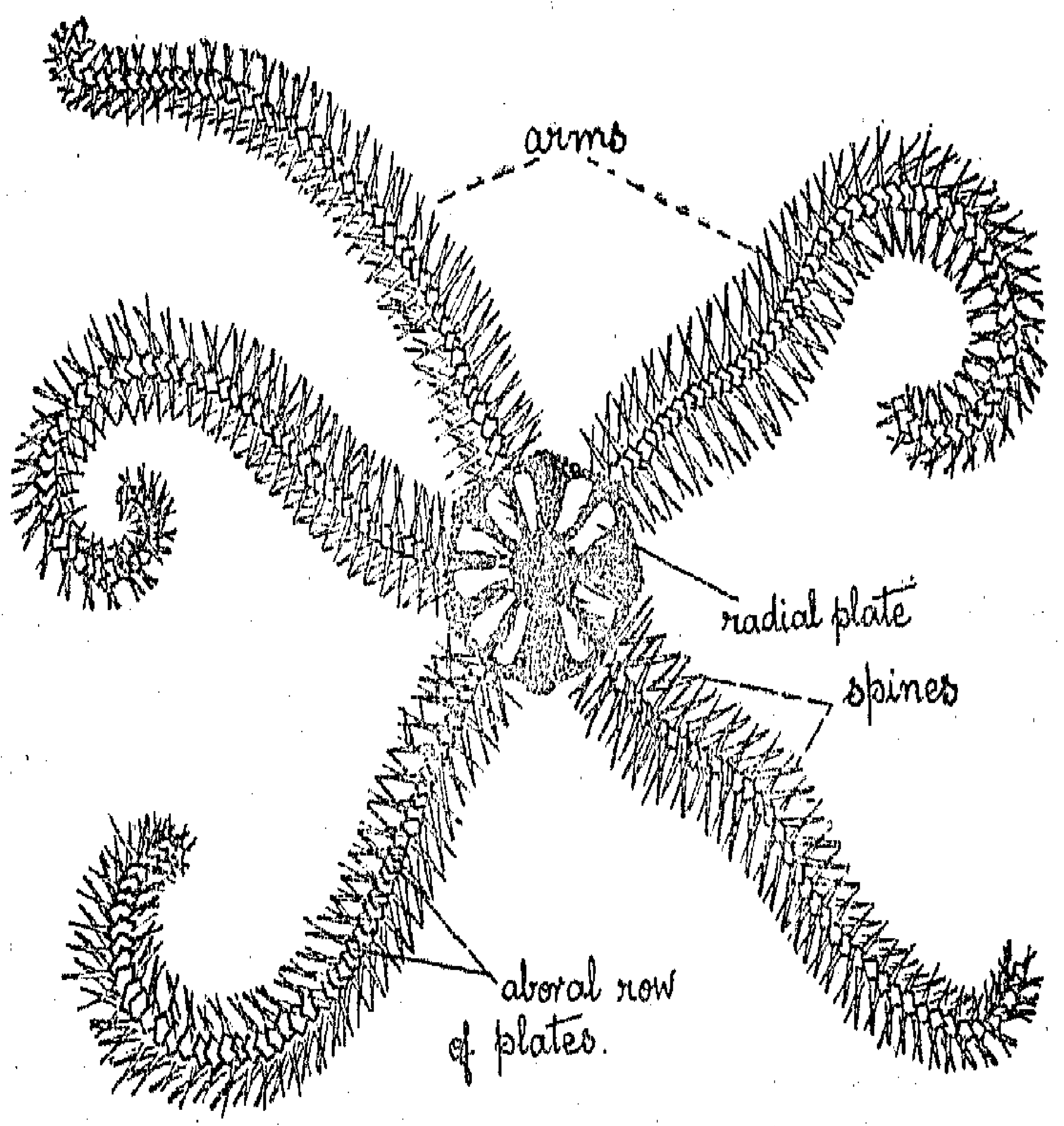

Fig. 331. Ophiothrix fragilis (Aboral view) (After Macbride).

also lie towards the oral side. The brittle stars are capable of rapid locomotion.

Class **Echinoidea**

Echinus (Sea-urchin) has a globular body with *mouth* and *anus* at the opposite poles. Round the mouth is a leathery area the *peristome;* similarly the leathery area around the anus is the *periproct.* Leaving the peristome and the periproct, the entire body is covered by numerous cylindrical, solid, pointed movable spines. Small spinules are found around the basal region of spines. Minute stalked pedicellariae each with three jaws are found distributed amongst the spines. The pedicellariae are of various kinds, some are used as weapons of defence, some are of help in the capture of small animals to be utilised as food. Rounded bodies, probably sense organs known as *sphaeridia* are also found distributed here and there. Except the peristome and the periproct, the entire surface is enclosed in a *shell* or *corona* lying under the ciliated epidermis formed of precisely fitting plate like ossicles bearing rounded tubercles on the surface with which the spines articulate. There are two rows of *ambulacral plates* in each of the five radii and two rows of *inter-ambulacral plates* in each of the five inter radii. The *mouth* is surrounded by five inter radial teeth, the apices of which project through the mouth. The teeth are supported by a complex frame work known as *Aristotle's lantern* which encloses the lower part of the oesophagus.

The space inside the lantern is known as the lantern coelom which represents an enlarged perihaemal ring. The alimentary canal consists of an oesophagus, a stomach with a short caecum in the beginning; at either end of the stomach opens a small cylindrical tube known as *siphon*, the *intestine* and a narrower *rectum.* The sea-urchin feeds on sea-weed.

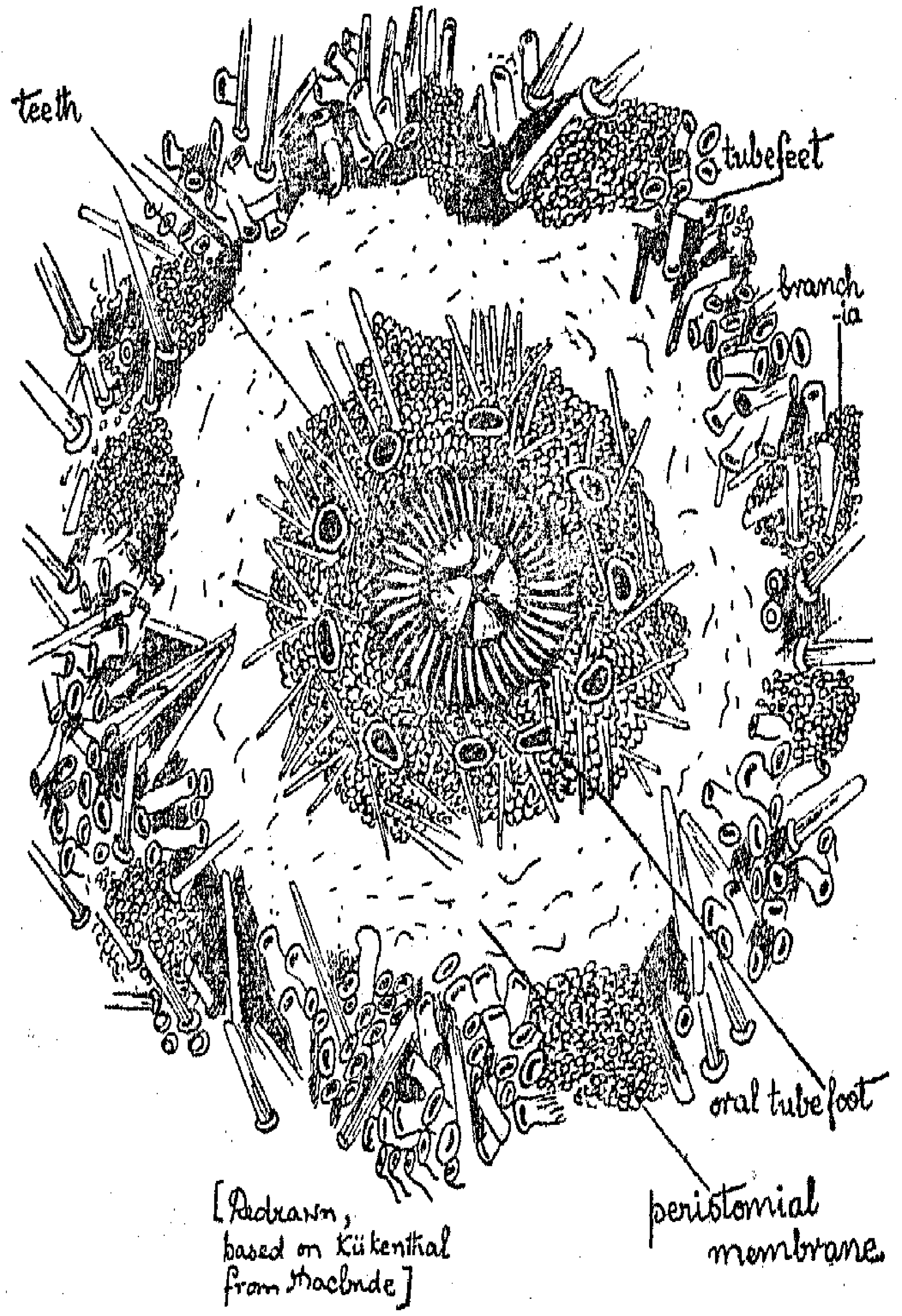

Fig. 332. Echinus esculentus oral view (Based on Kukenthal from Macbride).

The water-vascular system consists of an *uncalcified madreporic canal, a ring vessel* around the oesophagus, five *Tiedemann's bodies, five ambulacral vessels* and tube-feet. The ampulla communicates with each tube-foot by two canals. Both *tube-feet* and *spines* are used in locomotion. A *lacunar system* is found. The *gonads* are five masses lying in the perivisceral cavity one near each genital plate. *Respiration* occurs by tube-feet and ten shrub like (branched) pouches, the *dermal branchiae,* a pair opposite each interambulacral area at the periphery of the peristome,

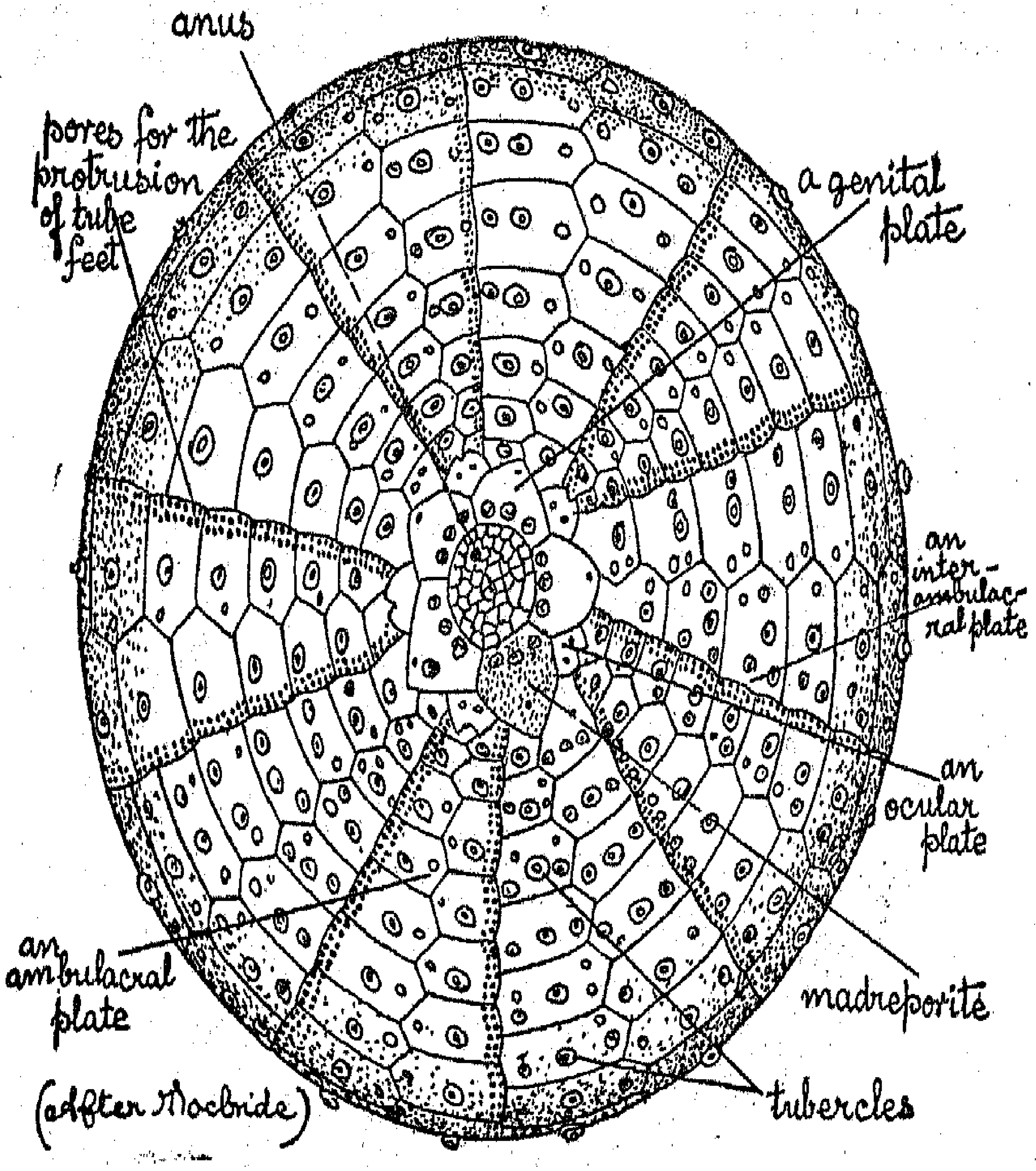

Fig. 333. Corona of Echinus (Redrawn after Macbride.)

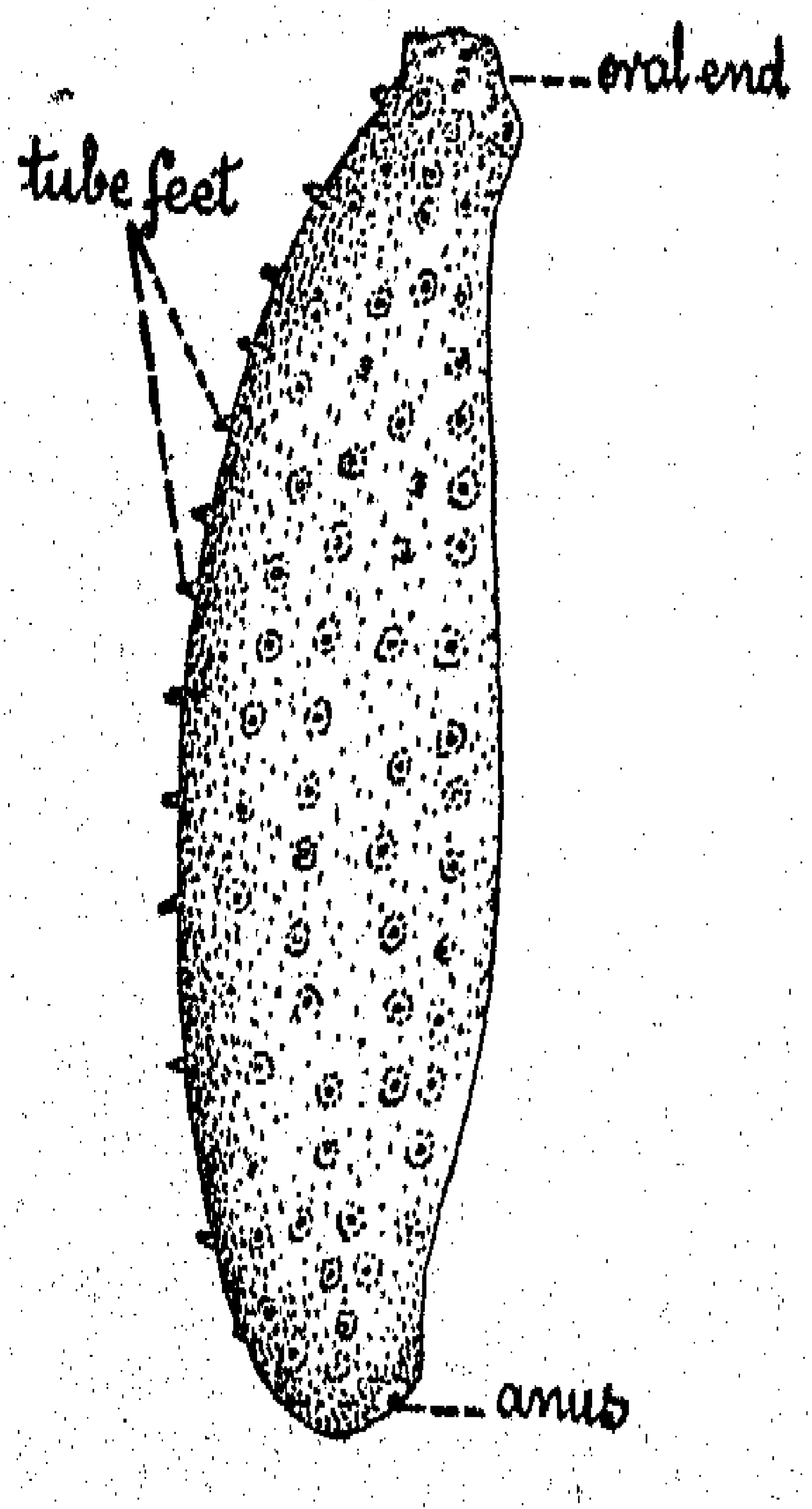

Fig. 334. Holothuria.

Class **Holothuroidea.**

Holothuria (Sea-cucumber) has an elongated cylindrical body. The muscular bodywall contains scattered spicules or small ossicles. Spines and pedicellariae are absent. Arms are completely absent. The adult lacks an external madreporite. There is a circlet of large oral tentacles which represent modified tube-feet. In *Holothuria*, the madreporite is internal. The primary madreporite and the gonad, both lie in one inter-radius; the other gonads are lost. The *mouth* and the *anus* lie at opposite ends. As a result, the body exhibits a rudimentary bilateral symmetry. In *Holothuria*, there is a conspicuous bilateral symmetry.

The inter-radius bearing the madreporite and the two adjoining radii on its sides form the *dorsal side* of the animal.

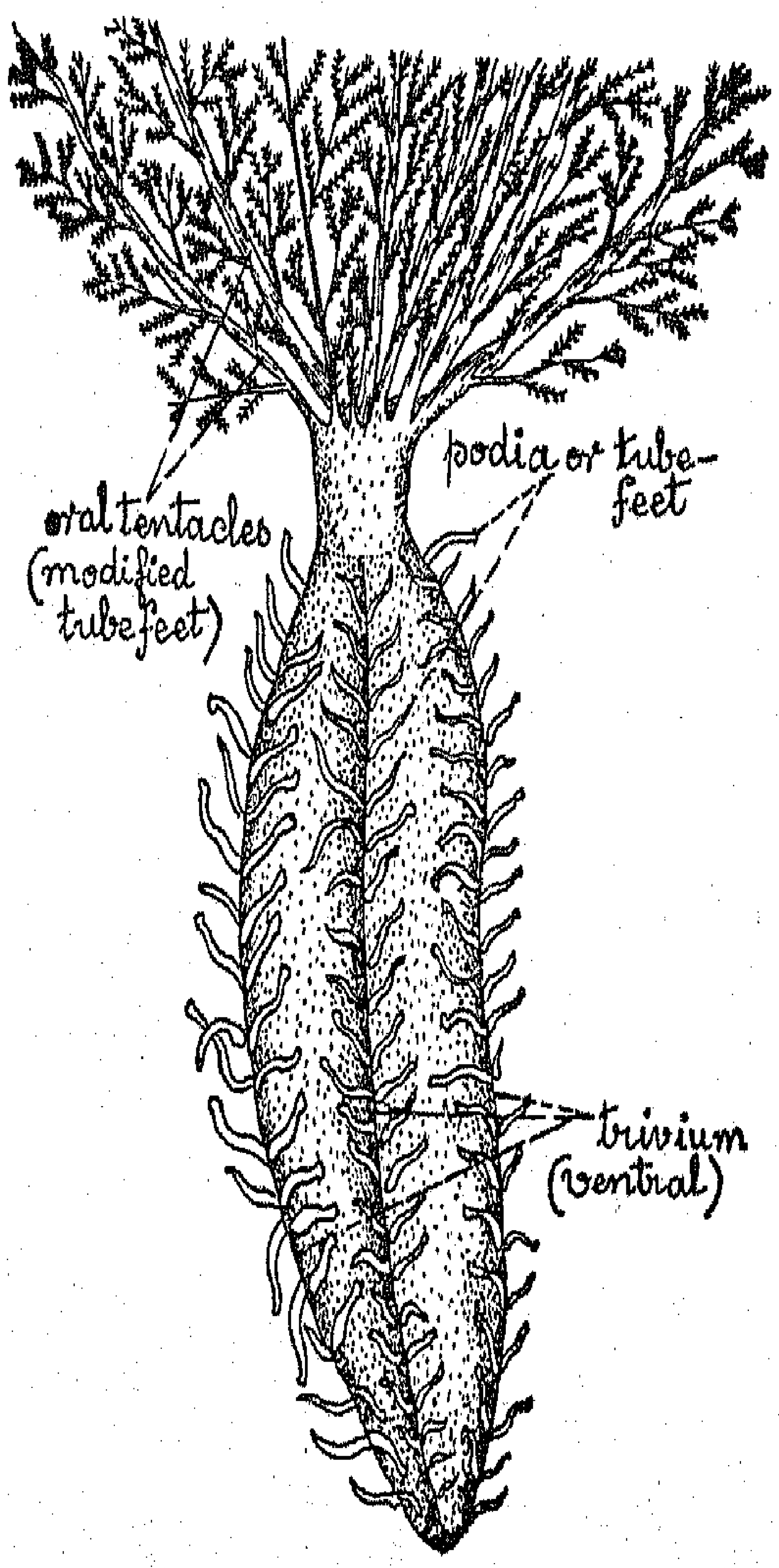

Fig. 335. Cucumaria.

The rest of the three radii form the flattened ventral side. The animal rests on the ground with its long axis parallel to the surface and with its ventral surface applied to it. The *tube-feet* of the ventral side are suctorial and aid in locomotion while *those* of the dorsal side are pointed forming sensory papillae. The tube feet are not confined to the radii thus obscuring the radial symmetry from the outside. (In *Cucumaria*, the tube-feet are confined to radii.) A circlet of ten tentacles which are modified tube-feet protrudes out through the mouth; these tentacles are tree-like with a central stem bearing short branches which again are branched. These contractile and sensitive tentacles are readily withdrawn inside the mouth when the animal is disturbed.

The bodywall has internally a *coelomic epithelium* lining the coelom; and outer to it two muscle-layers covered with a hard integument. The inner muscle layer is represented by five flattened bands, one in each ambulacral area; the outer muscle layer is continuous. In close contact with each of these muscle bands, lies a *radial ambulacral vessel*; *these* arise from the ring vessel which surrounds the beginning of the oesophagus. The tentacles receive branches from the radial vessels. Along the radii they communicate with tube-feet each of which has an ampulla. A large *Polian vesicle* and one or more short madreporic canals also arise from the ring-vessel of the water vascular system. The madreporic canals terminate in a perforated extremity inside the coelomic cavity; there is no external madreporite. Five *radial nerves* arising from a nerve ring (surrounding the mouth) constitute the nervous system. The axial organ is represented only by a *genital stolon* near the gonoduct.

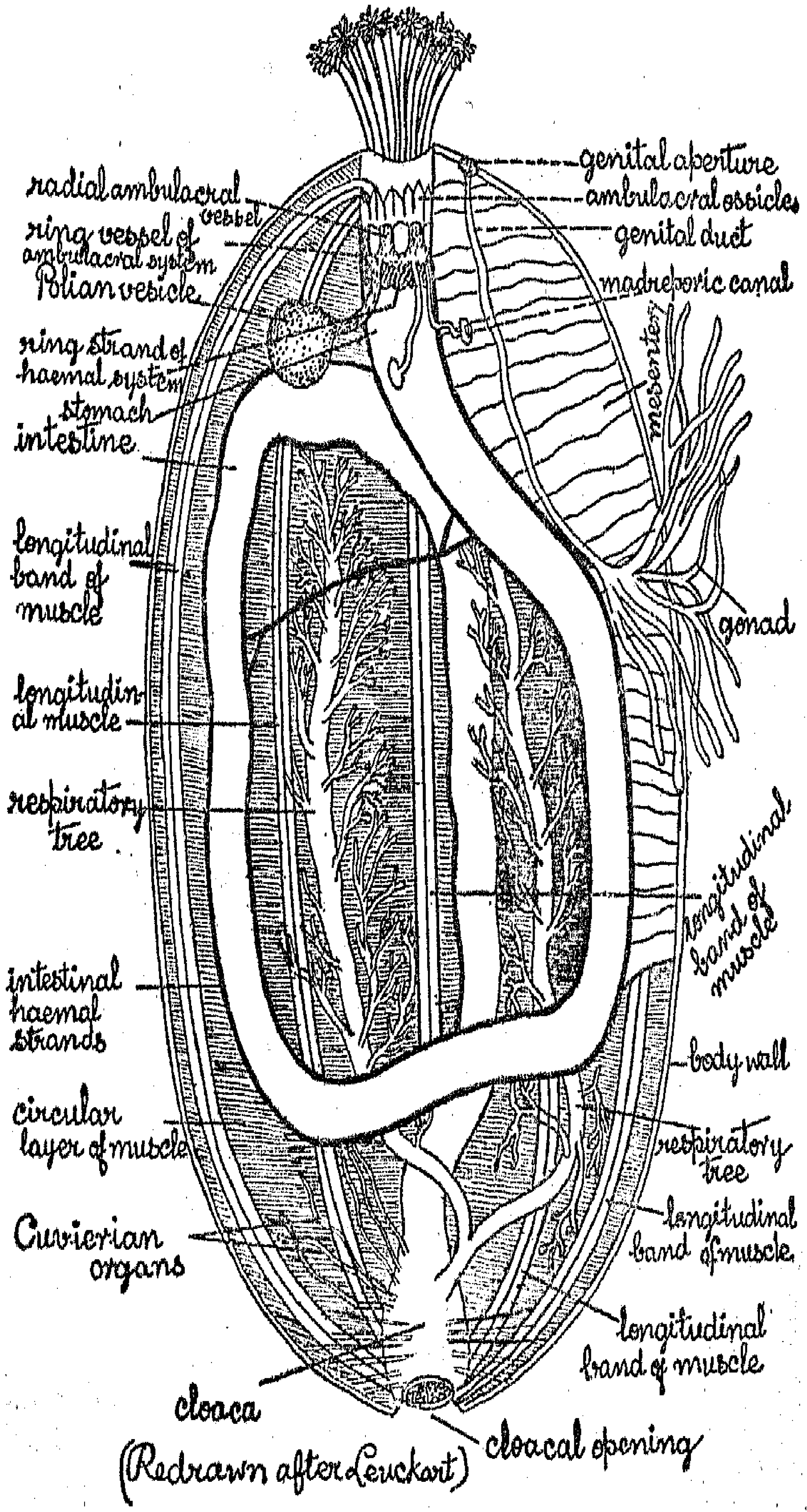

Fig. 336. Diagram showing internal organs of a Holothurian. (Based on Leuckart from Parker and Haswell).

In the **alimentary canal**, there is an *oesophagus*, a *stomach* and *intestine* followed by a short wide *cloaca* into which open two branched *respiratory trees*, their ramifications terminating in thin walled *ampullae*. The cloaca contracts and as a result, sea-water passes through these ampullae into the coelomic cavity and thereby conveys oxygen to the coelomic fluid and therefrom to other organs. Some of the lower branches of the respiratory tree form special tubes covered with a sticky substance; these tubes are known as *Cuvierian organs*. When the animal is attacked, these organs are driven out, due to a sudden contraction of the muscles of the bodywall which causes a pressure in the coelomic fluid. Due to this pressure, the cloaca is ruptured and the *Cuvierian organs* are forced out to the exterior where they form a *mass of sticky threads* in the sea-water *which* entangles the attacker.

Crinoidea (Subphylum-**Pelmatozoa**).

Antedon (Feather star) occurs in shallow waters. A *stalk* is found only in the young animal. When the animal becomes an adult, it detaches and swims away by waving movements of its arms. The tube-feet are not used in locomotion. At the base of the stalk are found slender curved appendages known as *cirri*.

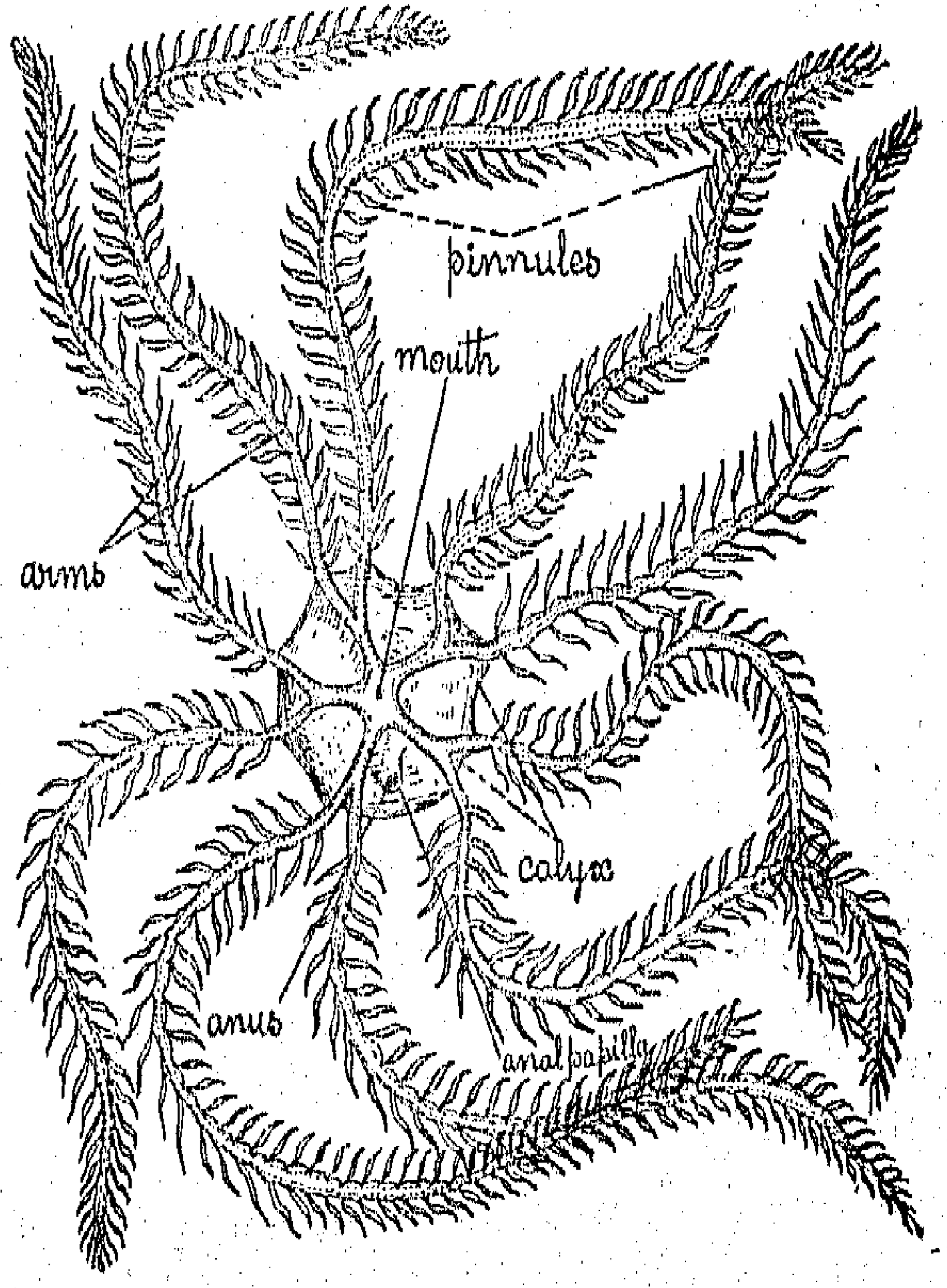

Fig. 337. Antedon (Oral view).

There is a central disk and the five arms are bifurcated at their base. The arms are feather-like and hence the name 'Feather Star'. The *cirri* can anchor the animal temporarily to substratum. The mouth as well as the anus lie on the oral surface. From the mouth five ciliated *food grooves* (the ambulacral grooves) radiate outwards each of which bifurcates at the base of the arm. On the aboral side is found a *centrodorsal ossicle* in the centre which represents the stump of the stalk and which is fringed with numerous cirri.

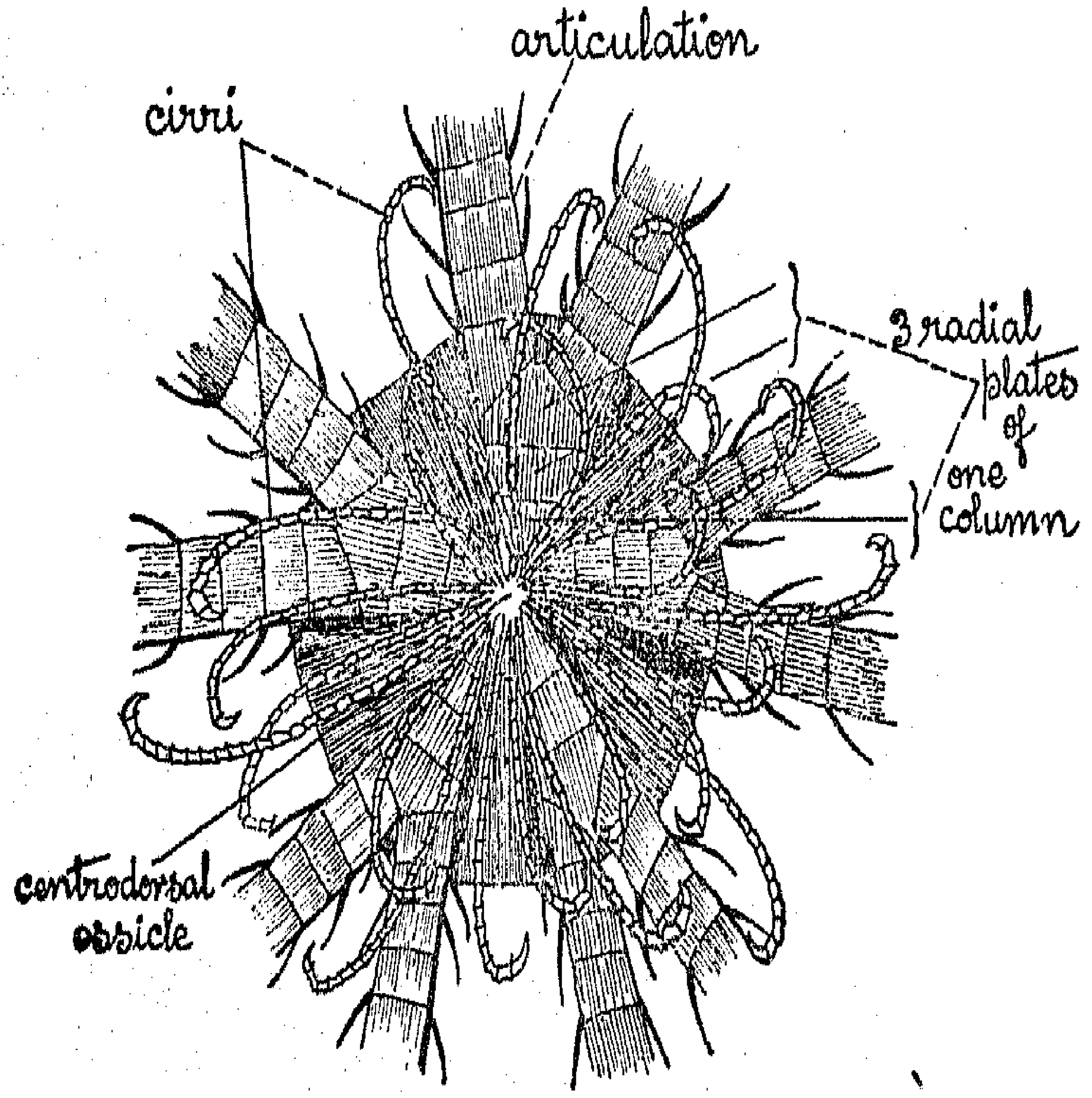

Fig. 338. Aboral view of Antedon (Based on Macbride).

The cilia of the *food grooves* create a food current which carries food particles towards the mouth. On each side of the food grooves there is found a row of ciliated finger-shaped *tube-feet* or *podia*. The *podia* also serve a respiratory function; those around the mouth are *sensory*.

The dermis of the aboral side has a skeleton of ossicles while that of the oral side is soft and leathery. The arms and cirri also have ossicles.

The alimentary canal consists of an oesophagus, stomach, intestine and terminal rectum. Rectum contracts and dilates so that water is drawn in and expelled out and in this manner intestinal respiration occurs.

The *water-vascular system* consists of a *ring vessel* around the mouth, a series of *radial vessels* corresponding to the ambulacral grooves, *podia* and *tentacles*. A number of *water-tubes* arise from the ring vessel, hang into the coelom into which they open. Many *vessels* also lead through the oral wall of the disc; these have small ciliated openings. The *water tubes* and the *vessels* represent the *madreporic canal*.

The 'Feather-star' has a free-swimming *ciliated larval stage* which is followed by a fixed stalked stage known as the *pentacrinoid larva*. From this, the adult is formed by the elongation of arms and the development of cirri.

THE END

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